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RTD Interim Report 8-112 (IV)
August 1964

EXTRUDING AND DRAWING MOLYBDENUM TO COMPLEX THIN H-SECTION

Allegheny Ludlum Steel Corporation
Research Center

Contract AF 33(657)-11203
RTD Project: 8-112

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Fourth Interim Technical Engineering Report 117p
1 May 1964 to 31 July 1964

Sixteen H-shaped extrusions (14 TZM and 2 stainless) were made with new support tooling. No failure or distortion occurred in the tooling, regardless of liner pressure up to 237,000 psi. Reasonable quality and dimensional run-out were found in TZM extrusions at a reduction ratio of 43:1 from a 3200F billet temperature with the use of flame-sprayed zirconia dies. Similar extrusions from 3350F were poor.

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FOREWORD

This Fourth Interim Technical Engineering Report covers the work performed under Contract AF 33(657)-11203 from 1 May 1964 to 31 July 1964. It is published for technical information only and does not necessarily represent the recommendations, conclusions or approval of the Air Force.

This contract with the Research Center of the Allegheny Ludlum Steel Corporation, Brackenridge, Pennsylvania, was initiated under RTD Manufacturing Technology Division Project 8-112, "Extruding and Drawing Molybdenum to Complex Thin H-Section." It is administered under the direction of Mr. C. S. Cook of the Metallurgical Processing Branch (MATB), Manufacturing Technology Division, Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio.

Responsible for the execution of the work and preparation of the report was P. A. Santoli, High Temperature Alloy and Tool Steel Section, Research Center, Allegheny Ludlum Steel Corporation. Other personnel who contributed to the work were F. H. Tansey, F. S. Turner, D. L. Byrne, P. R. Borneman and the staff of the Service Department of the Allegheny Ludlum Research Center.

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ABSTRACT-SUMMARY
Fourth Interim Technical Engineering Report

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August 1964

EXTRUDING AND DRAWING MOLYBDENUM TO COMPLEX THIN H-SECTION

Allegheny Ludlum Steel Corporation
Research Center

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INTRODUCTION

The purpose of this program is to advance the State-of-the-Art of mc bdenum extruding and drawing to produce thin sections of molybdenum in the quality required for various Air Force mission-oriented systems. The measure of satisfactory accomplishment of this process development will be the production of acceptable H-shaped sections as can be circumscribed by a circle of approximat ly two inches diameter, to a thickness of 0.040-inch and to a length of 20 feet. This program is sponsored by the Aeronautical Systems Division of AFSC.

The program approach has been outlined in two phases:

Phase I - Development of the Extrusion Operation

Phase II - Development of the Drawing Operation

A commercial arc-cast molybdenum-base alloy designated as TZM is being used in this program. This alloy has the following analysis range:

	Molybdenum and Weight Percent
Titanium	0.40 - 0.55
Zirconium	0.06 - 0.12
Carbon	0.01 - 0.04

The first H-shaped extrusions of stainless steel and TZM were made during the previous report period and shown in the Third Interim Technical Engineering Report. Support tooling failed severely during these extrusions. New support tooling was made to double die support. This tooling was used during this report period and the results are reported herein.

SUMMARY AND CONCLUSIONS

Sixteen H-shaped extrusions (14 TZM and 2 stainless) were made with new support tooling. No failure or distortion occurred in the tooling, regardless of liner pressure up to 237,000 psi. Reas ıble quality and dimensional runout were found in TZM extrusions at a reduction ratio of 43:1 from 3200F billet temperature with the use of flame-sprayed zirconia dies. Similar extrusions from 3350F were poor.

The use of presse∫ and sintered solid zirconia nibs was demonstrated successfully for the extrusion of "H" shapes. Dimensional runout for both stainless and TZM was remarkably good and liner pressures were lower than that required for extrusions with segmented, coated dies.

DISCUSSION

A. TZM Extrusion Billet Material

Arc-cast and powder metallurgy billet stock of TZM have been purchased for extrusion billets. Available data from suppliers and evaluation results for these materials were given in previous interim technical engineering reports.(1),(2),(3)

A laboratory investigation is in progress to determine the conditions under which precipitation in TZM can occur by heating and cooling. These results, in turn, will be helpful in understanding the microstructural changes observed in extruded material.

Transverse hollow specimens (3/4-inch OD by 5/8-inch ID by 3/4-inch long) were machined from as-received billet stock from Heat 7534. These specimens were heated rapidly in argon to 3000F, 3200F, 3400F, 3600F, 3800F and 4000F without dwell time at each temperature, followed by rapid cooling by a heavy flow of argon to below 2000F within two minutes.

Figures 1 to 3 show the heat treated microstructures after electropolishing in Disa A-3 solution and electroetching in a solution of 10 percent sodium hydroxide. Figure 2 in the Second Technical Engineering Report(2) shows the etched microstructure of Heat TZM-7534 in the as-received recrystallized condition.

The results of microstructural examination showed that changes in the microstructure of TZM occurred by rapidly heating and cooling. It was observed also that a noticeable decrease in the amount of carbide and hardness occurred by raising the temperature from 3000F to 3200F. These changes were also accompanied by spheroidization of the remaining carbides. Whether changes in the microstructure at the higher temperatures resulted from solutioning followed by precipitation has yet to be determined. Previous round extrusions already reported(2) showed similar microstructural changes suggesting heating and cooling rather than deformation as the strong influence on microstructural changes in TZM.

This study of heating and cooling TZM will continue with different dwell times at temperature. Heat treating and forging TZM prior to extrusion into "H" shape will be established on the basis of this study.

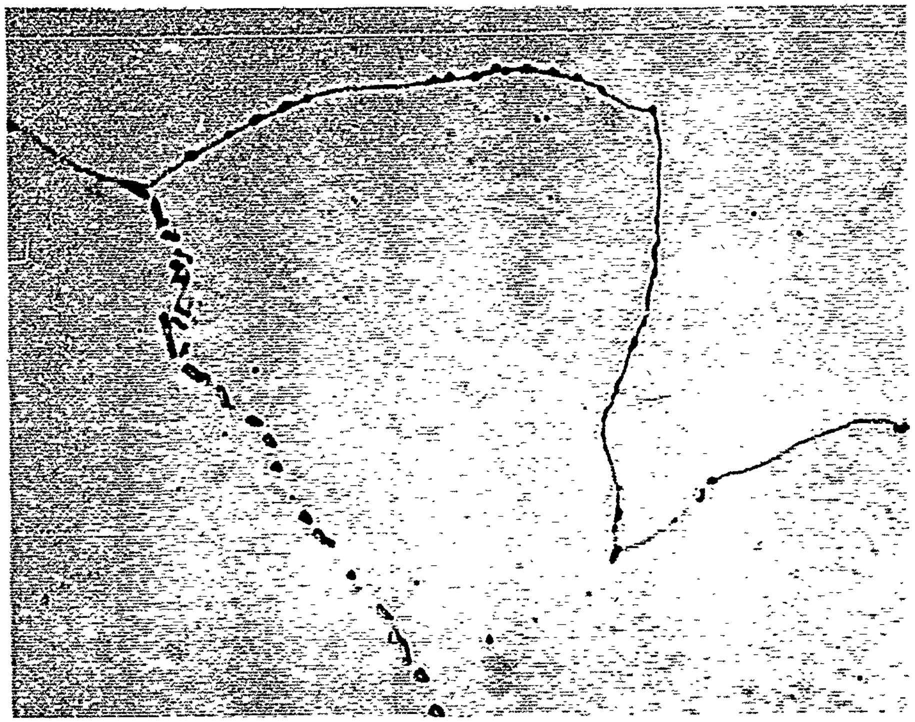
B. Extrusion Equipment and Procedure

1. Extrusion Press

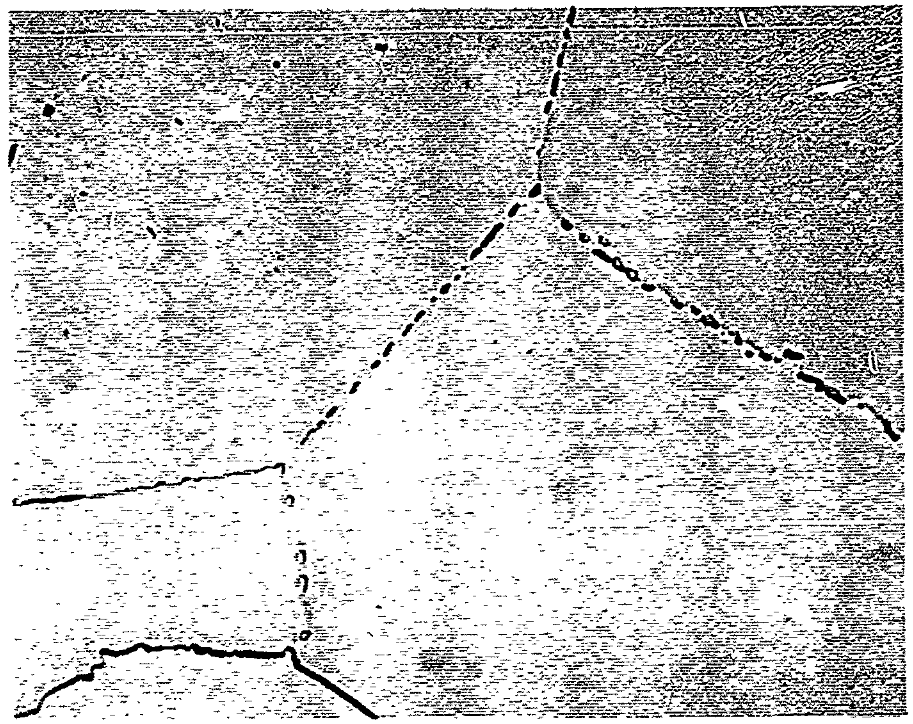
Description of the extrusion press was given in the previous interim technical engineering report.(2)

2. Billet Heating and Handling

Description of billet heating and handling was given in the previous interim technical engineering report.(2)



3000F
Vickers (10 kg) 194
ASTM Grain Size 5 to > 1

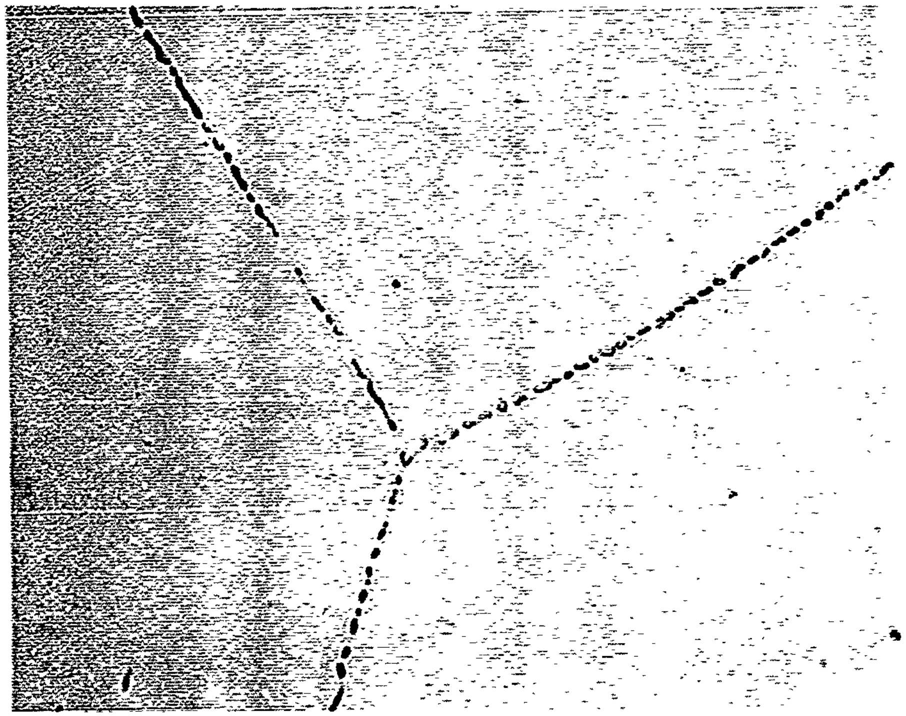


3200F
Vickers (10 kg) 176
ASTM Grain Size 3 to > 1

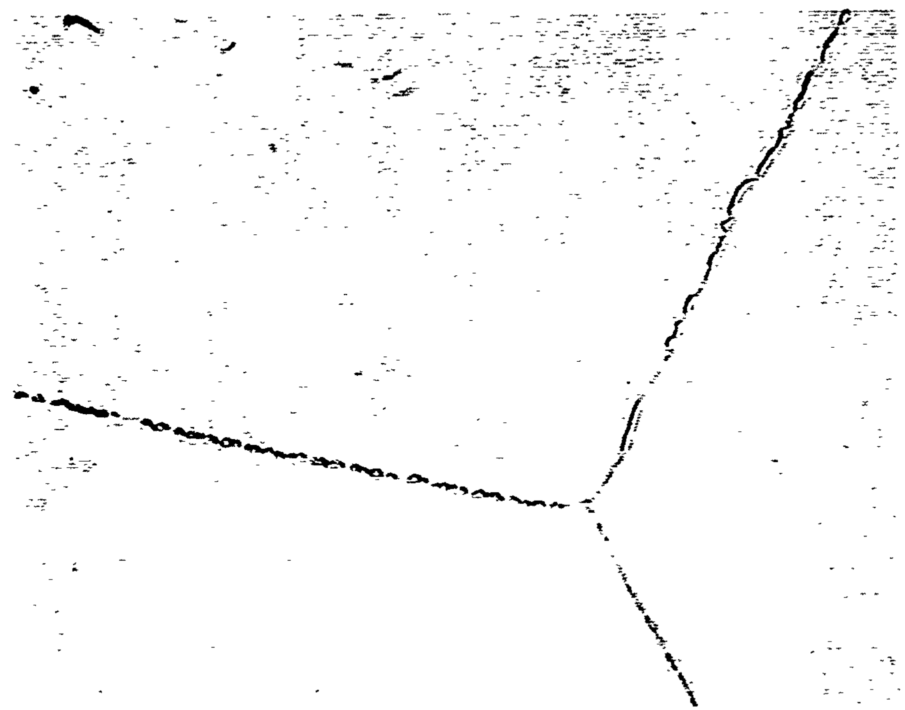
Etchant: 10% NaOH - Electrolytic
Magnification: 1500X

FIGURE 1

TZM From Heat TZM-7534 Rapidly Heated to 3000F and 3200F in Argon Without Dwell Time at Temperature



3400F
Vickers (10 kg) 186
ASTM Grain Size 2 to > 1

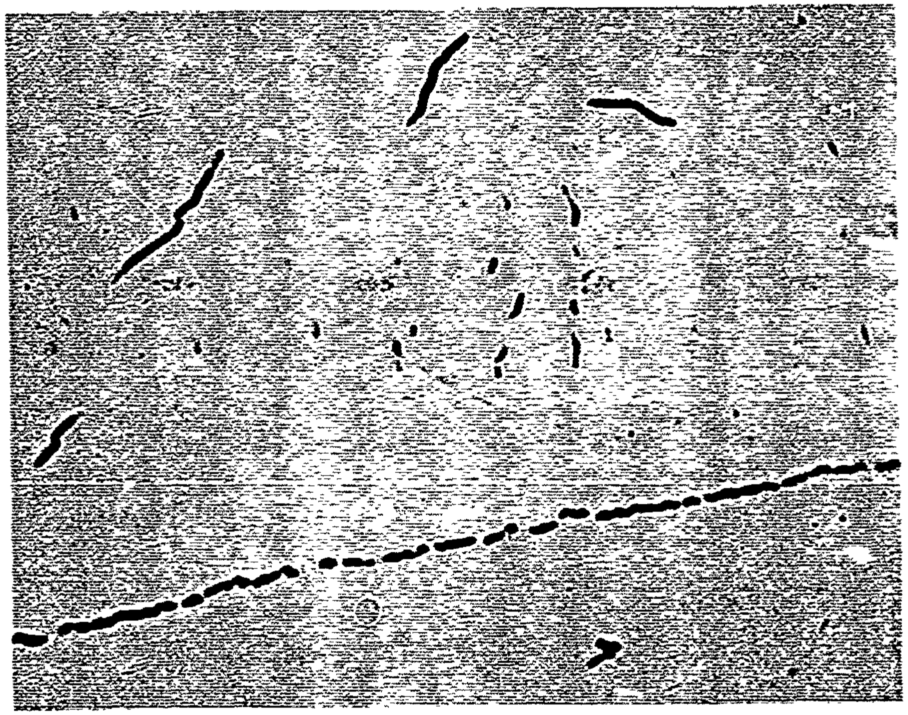


3600F
Vickers (10 kg) 185
ASTM Grain Size 2 to > 1

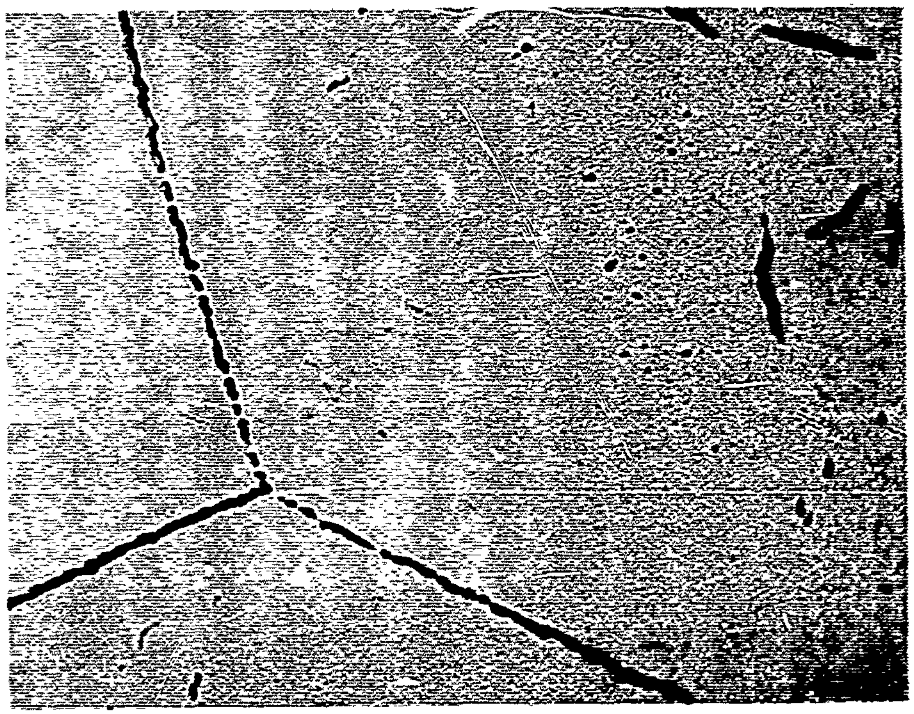
Etchant: 10% NaOH - Electrolytic
Magnification: 1500X

FIGURE 2

TZM From Heat TZM-7534 Rapidly Heated to 3400F and 3600F in Argon Without Dwell Time at Temperature



3800F
Vickers (10 kg) 191
ASTM Grain Size 1 to > 1



4000F
Vickers (10 kg) 185
ASTM Grain Size > 1

Etchant: 10% NaOH - Electrolytic
Magnification: 1500X

FIGURE 3

TZM From Heat TZM-7534 Rapidly Heated to 3800F and 4000F in Argon Without Dwell Time at Temperature

3. Die Design and Materials

H-shaped dies were prepared with flame-sprayed ceramic segments and solid zirconia nibs both of which were assembled in retainer rings. Table 1 is an outline of orifice openings, coating thickness and materials. Die design and typical dies were shown in previous interim technical engineering report.[3] Drawing numbers given in Table 1 pertain to die designs shown in Figures 4 through 8.

4. Lubrication

Proprietary compositions of lubricants as provided under license agreements are designated by code numbers.

Allegheny Ludlum is a licensee of Compagnie du Filage des Metaux et des Joints Curty (Cefilac), formerly known as Comptoir Industriel d' Etirage & Profilage de Metaux, Societe Anonyme, for the use of glass lubricants in extrusion processes and as such, is obliged under the terms of its license agreement to maintain as confidential certain features such as glass compositions and proprietary designs.

a. Billet Lubrication

Glass in powder form of -325 mesh was placed on the "glass" table. Heated billets at extrusion temperature were rolled through the glass and picked up practically all of it. Billet glass composition code numbers are listed in the extrusion data table given later in this report.

b. Die Lubrication

A glass pad was placed between the billet and die for each extrusion. The pad, 4-inch OD by 1/2-inch ID by 1-inch thick, was composed of glass fibers. Die glass composition code numbers are listed in the extrusion data table given later in this report. Die surface was precoated with Moly-Spray-Kote[4].

c. Liner Lubrication

Molykote G[5] was used for lubrication of the liner. This was applied by swabbing the liner ID with a cloth saturated with the lubricant.

C. Extrusion Data and Die Performance

Extrusion data for TZM H-shaped extrusions are given in Table 2. Dimensional checks as a measure of die performance for the extrusions are shown in Tables 3 through 18.

The first H-shaped extrusions were accompanied by support tooling failures.[3] New support tooling was made and used for the extrusions accomplished during this report period. Support tooling failures did not occur during these extrusions except for one spacer that cracked under pressure from foreign matter stuck between it and the die.

TABLE 1

H-Shaped Dies

Die Code No.	Drawing Number	Die Nib Material(1)	Retainer Ring Material	Die Orifice Dimensions: Opening	Die Orifice Dimensions: Flange Width	Die Orifice Dimensions: Height	Average Reduction Ratio(2)	Description(3)
H-DM25	B-0558-1	Potomac M	Almar 18-300	.058-.061	1.749	.995	40.8:1	20° Basic Angle, 3/16 FR
H-DM26	B-0558-1	Potomac M	Almar 18-300	.057-.062	1.750	.996	44.9:1	20° Basic Angle, 1/32 FR
H-DM27	B-0558-1	Potomac M	Potomac M	.061-.067	1.751	.998	41.1:1	20° Basic Angle, 1/32 FR
H-DM28	B-0558-1	Potomac M	Potomac M	.070	1.750	.999	38.4:1	20° Basic Angle, 1/32 FR
H-DM29	B-0558-1	Potomac M	Potomac M	.062	1.750	.999	45.6:1	20° Basic Angle, 1/16 FR
H-DM34	B-0581-1	Potomac M	Potomac M	.057-.061	1.750	.996	41.5:1	30° Basic Angle, 1/32 FR
H-DM32(4)	B-0581-1	Potomac M	Potomac M	.059-.062	1.752	.998	43.5:1	30° Basic Angle, 1/32 FR
H-DM33	B-0558-1	Almar 18-300	Almar 18-300	.079-.082	1.774	1.018	34:1	20° Basic Angle, 1/32 FR
H-DM34	B-0558-1	Almar 18-300	Almar 18-300	.064-.066	1.750	.996	41.5:1	20° Basic Angle, 1/32 FR
H-DM35	B-0581-1	Almar 18-300	Almar 18-300	.064-.065	1.749	.996	41.8:1	30° Basic Angle, 1/32 FR
H-DM36	B-0581-1	Almar 18-300	Almar 18-300	.061-.067	1.751	.998	40.9:1	30° Basic Angle, 1/32 FR
H-DM37	B-0658-1	Potomac M	Almar 18-300	.059-.062	1.752	.999	44.9:1	30° Basic Angle, 1/32 FR
H-DM38	B-0658-1	Potomac M	Almar 18-300	.067-.072	1.763	.999	38.1:1	30° Basic Angle, 1/32 FR
H-DM39	B-0655-1	Potomac M	Almar 18-300	.064-.068	1.753	.999	40.3:1	30° Basic Angle, 1/32 FR
H-DM48	B-0583	Zirconia	Almar 18-300	.063-.068	1.774	1.017	40.3:1	30° Basic Angle, 1/32 FR
H-DM49	B-0583	Zirconia	Almar 18-300	.062-.067	1.776	1.018	42.2:1	30° Basic Angle, 1/32 FR
H-DM50	B-0583	Zirconia	Almar 18-300	.067	1.774	1.015	40.3:1	30° Basic Angle, 1/32 FR
H-DM51	B-0583	Zirconia	Almar 18-300	.057-.062	1.773	1.017	45.6:1	30° Basic Angle, 1/32 FR
H-DM52	B-0653-1	Potomac M	Potomac M	.057-.064	1.753	.998	44.2:1	40° Basic Angle, 1/32 FR
H-DM53	B-0558-1	Potomac M	Potomac M	.076-.078	1.749	1.001	34.8:1	20° Basic Angle, 1/32 FR
H-DM54	B-0558-1	Potomac M	Potomac M	.097-.099	1.747	1.010	38:1	20° Basic Angle, 1/32 FR

(1) Potomac M and Almar 18-300 with flame-sprayed zirconia in about .035-inch thickness

(2) From liner diameter of 3-7/8 inches

(3) FR = fillet-radius

(4) Flat entry faces to fillet-radii

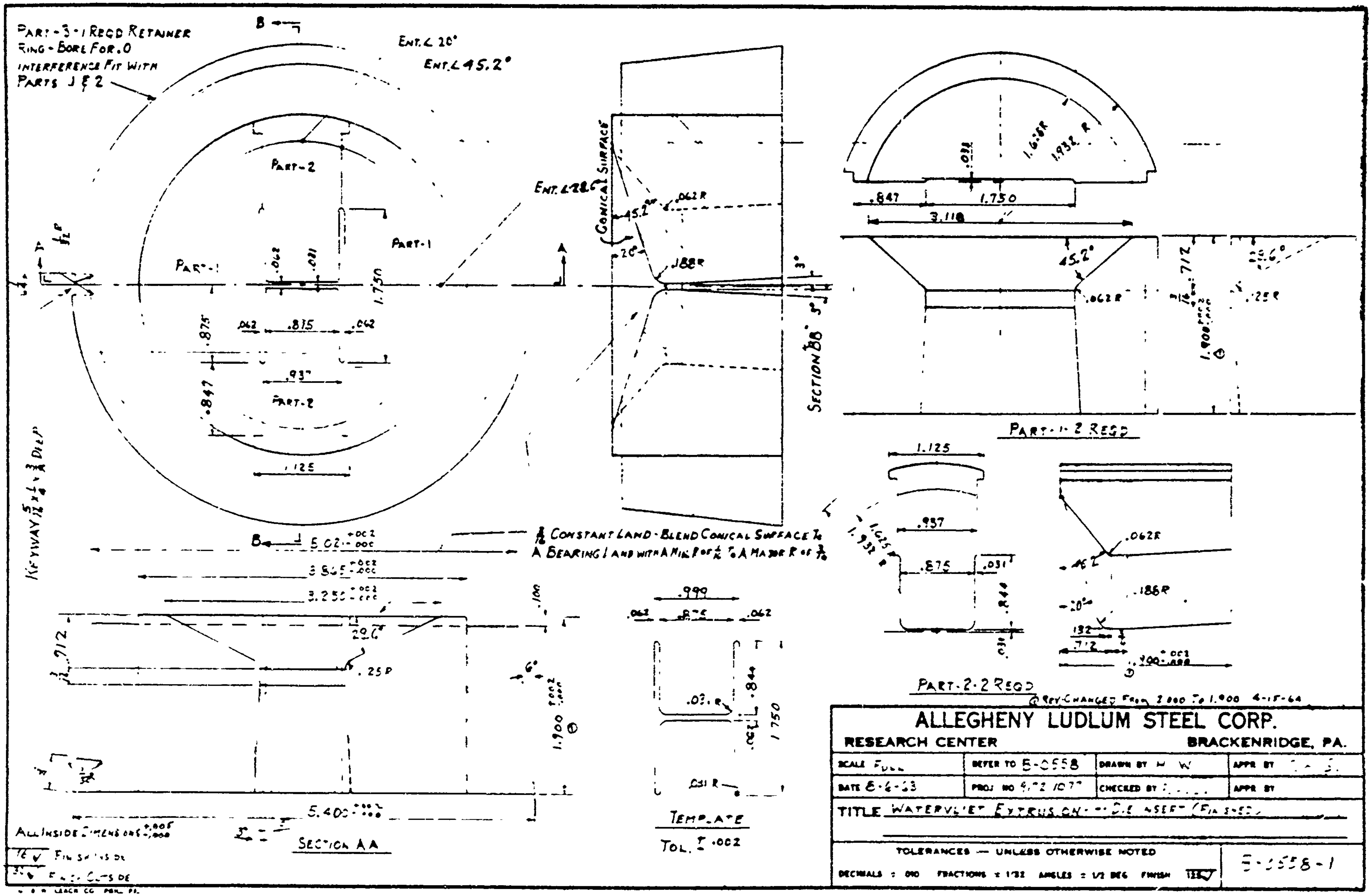


FIGURE 4

Die Design of 140-Degree Basic Angle (Drawing No. B-0558-1)

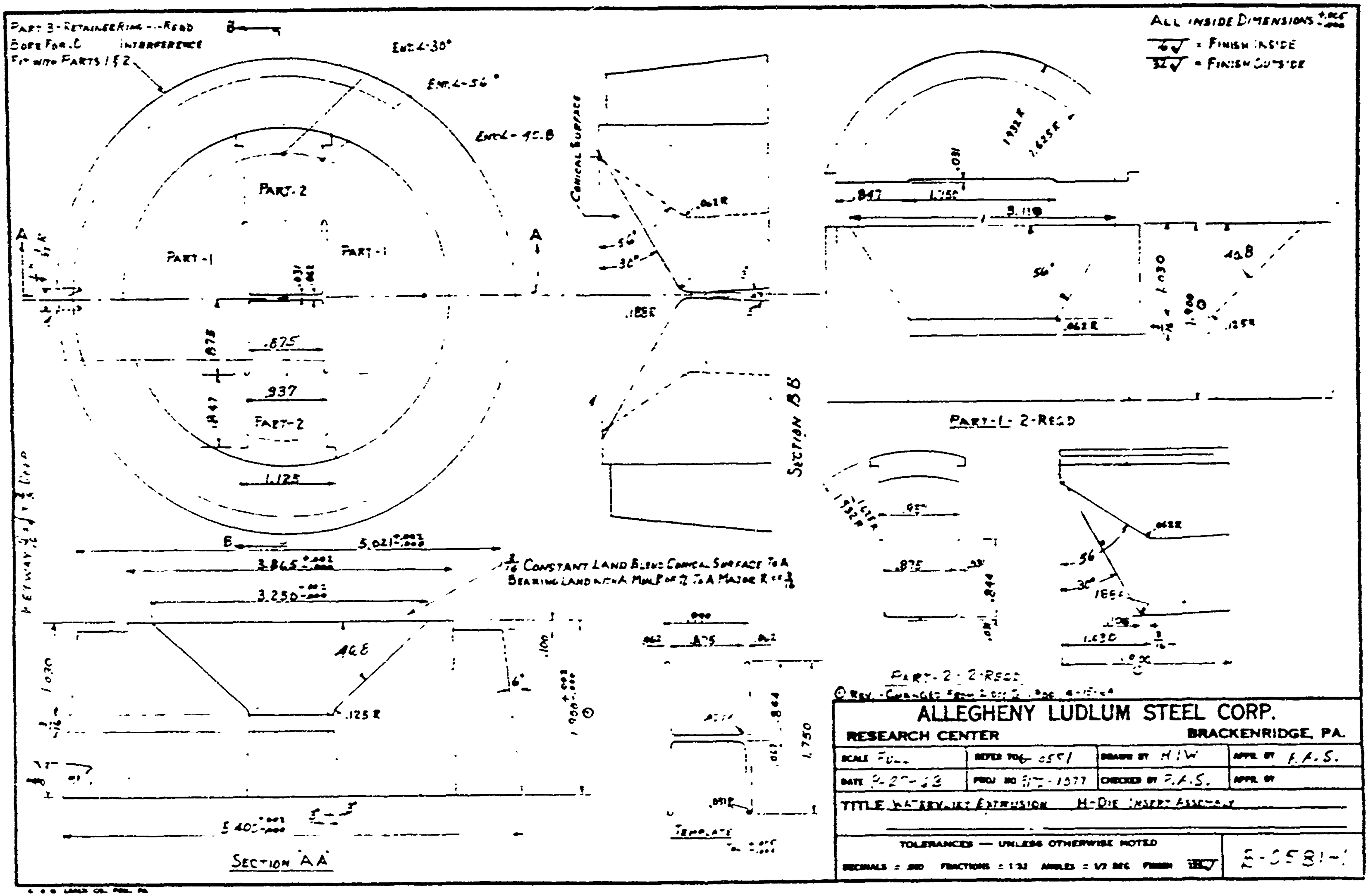


FIGURE 5

Die Design of 120-Degree Basic Angle (Drawing No. B-0581-1)

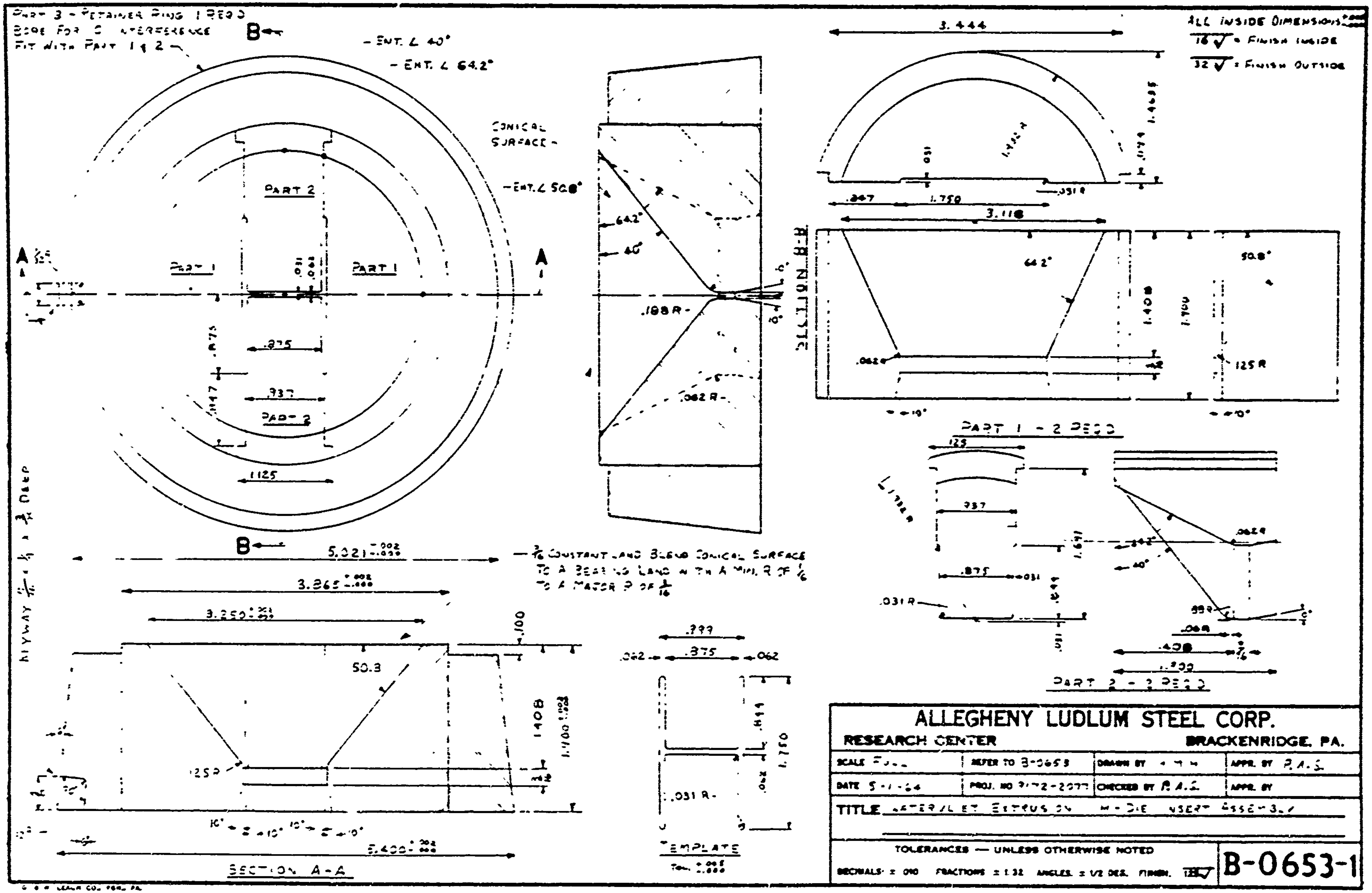


FIGURE 6

Die Design of 100-Degree Basic Angle (Drawing No. B-0653-1)

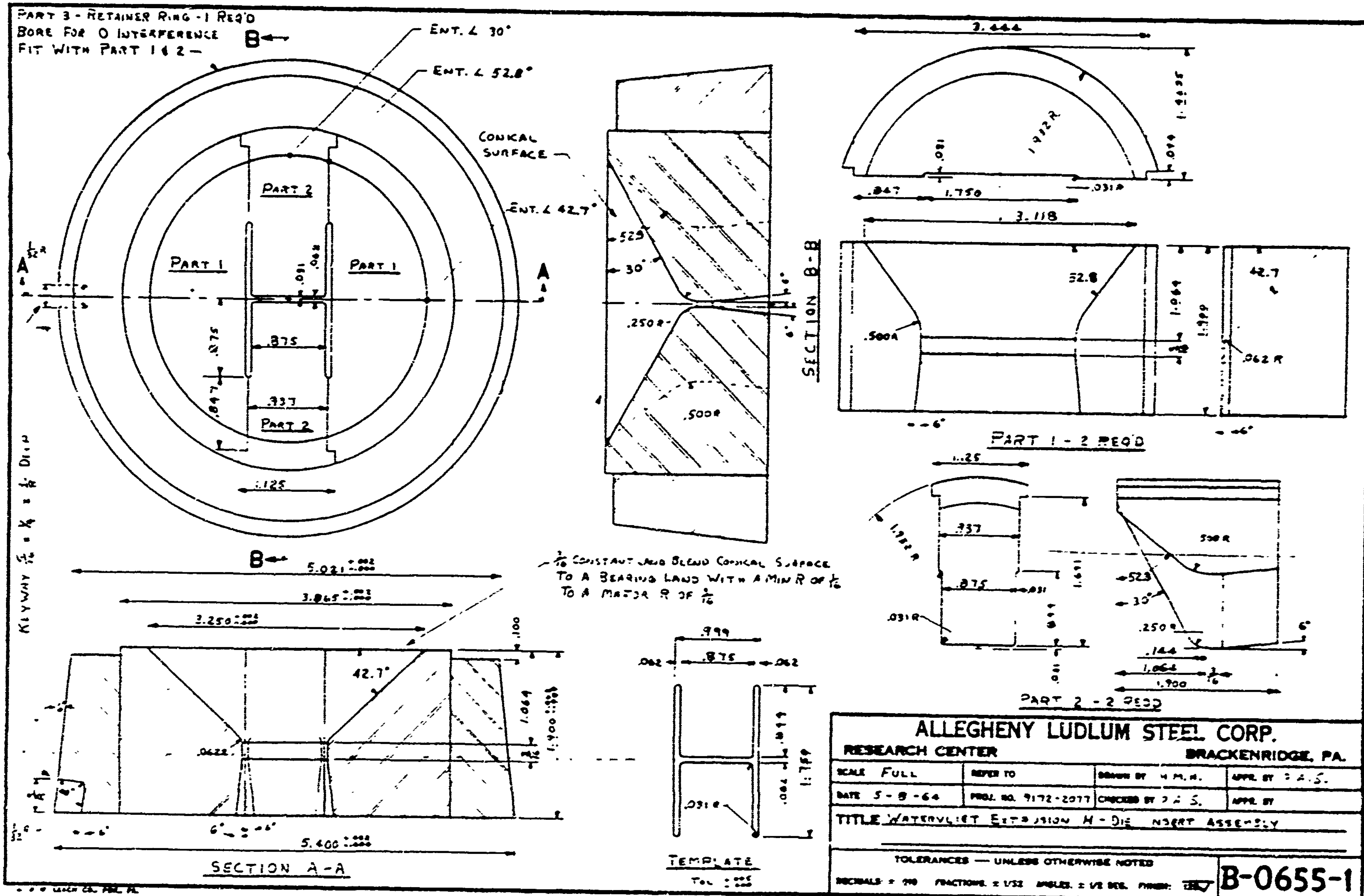


FIGURE 7

Die Design of 120-Degree Basic Angle and Modified Entry Radii (Drawing No. B-0655-1)

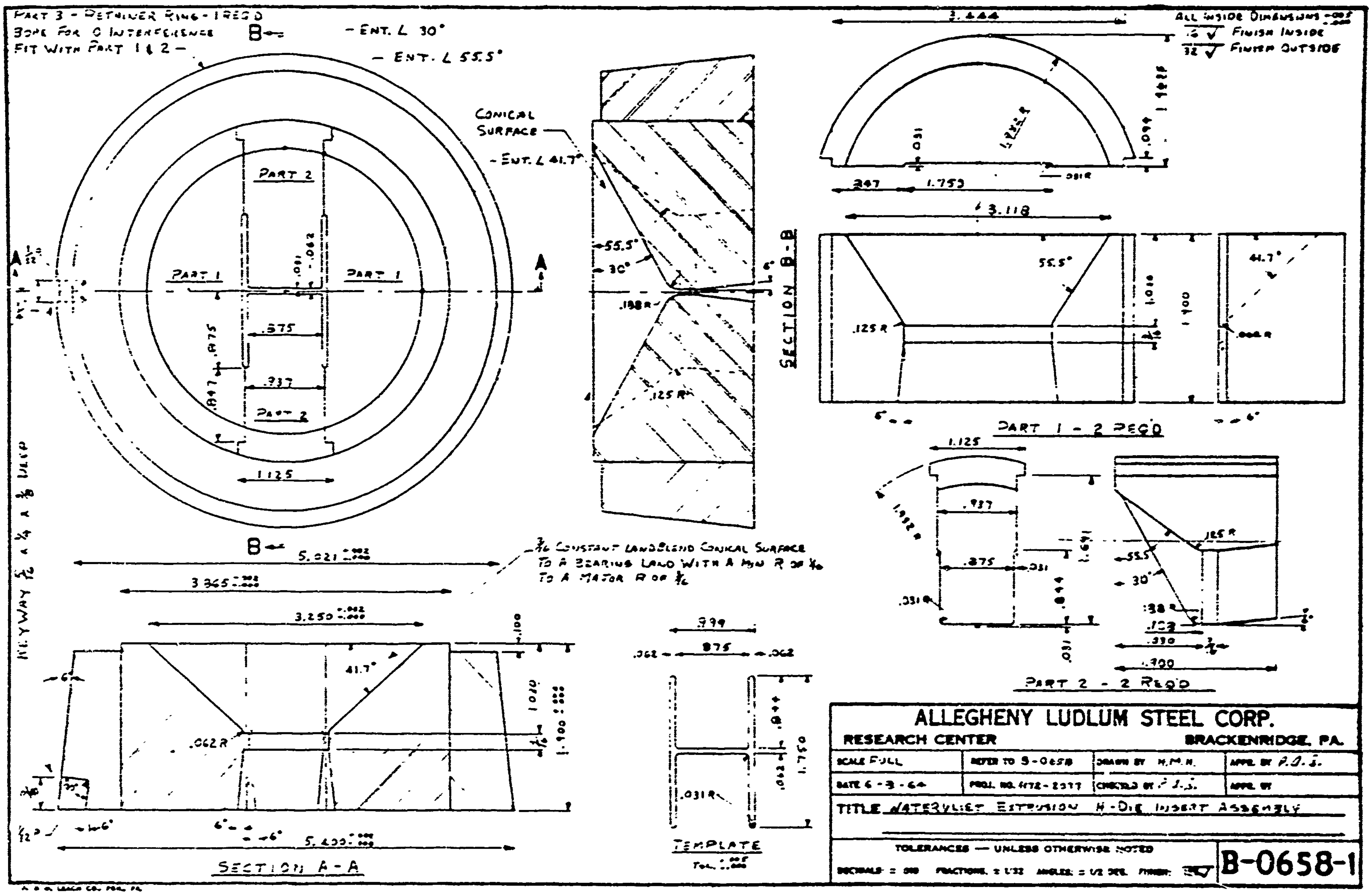


FIGURE 8

Die Design of 120-Degree Basic Angle and Modified Entry Radii (Drawing No. B-0658-1)

TABLE 2

Extrusion Data

Extrusion Sequence Number	Billet Code Number	Billet Heat Number	Billet Size (in.) Diameter	Billet Size (in.) Length	Billet Heating Temp. (°F)	Billet Glass Composition Code Number	Die Code Number	Die Glass Composition Code Number	Reduction Ratio[1]	Maximum Liner Pressure (ksi)	Minimum Liner Pressure (ksi)	Maximum Resistance to Deformation[2] (ksi)	Minimum Resistance to Deformation[2] (ksi)	Remarks
27	--	3-36090[3]	3.725	5	2120	AL-26-35	H-DM26	AL-19-56	44.9:1	180	124	47.3	32.6	169 inches long, good surface, one edge torn.
28	H-M23	TZM-7549-B	3.725	5	3240	AL-44-45	H-DM27	AL-N-56	41.1:1	213	206	59.0	55.4	119 inches long, light striations, poor corners and fillets.
29	H-M24	TZM-7549-B	3.725	5	3220	AL-44-45	H-DM25	AL-N-56	40.8:1	226	206	60.9	55.5	128 inches long, good fillets, poor corners, glass rub-in.
30	H-M25	TZM-7549-B	3.725	5	3250	AL-44-45	H-DM28	AL-N-56	38.4:1	219	206	60.2	56.5	126 inches long, light striations,fair corners, little glass rub-in.
31	H-M26	TZM-7549-B	3.725	5	3225	AL-44-45	H-DM35	AL-N-56	41.8:1	219	203	58.7	54.5	100 inches long, glass rub-in, light striations, fair corners and fillets.
32	H-M27	TZM-7608	3.725	6	3150	AL-44-45	H-DM36	AL-N-56	40.9:1	214	201	57.6	55	132 inches long, poor surface. badly torn edges.
33	H-M28	TZM-7534	725	5	3220	AL-44-45	H-DM39	AL-N-56	40.3:1	225	219	60.9	59.2	176 inches long, glass rub-in. good fillets, poor corners.
34	H-M29	45-3	3.725	5.5	3200	AL-30-45	H-DM34	AL-N-56	41.5:1	227	206	61.0	55.4	153 inches long, good surface. poor corners. light glass rub-in
35	H-M30	45-4	3.725	5.5	3000	AL-30-45	H-DM32	AL-N-56	43.5:1	227	216	60.2	57.2	129 inches long, good surface and fillets.
36	H-M31	45-5	3.725	5	2800	AL-30-45	H-DM29	AL-N-56	45.6:1	227	219	59.5	57.4	108 inches long, good surface. fair corners and fillets.
37	H-M32	TZM-7549-A	3.725	7	3200	AL-30-45	H-DM37	AL-N-56	44.9:1	229	214	60.4	56.4	156 inches long, light striations, fair corners.
38	H-M33	TZM-7549-B	3.725	7	3350	AL-30-45	H-DM38	AL-N-56	38.1:1	227	173	62.4	47.5	176 inches long, poor surface
39	H-M34	TZM-7608	3.725	8	3200	AL-30-45	H-DM53	AL-N-56	34.8:1	227	193	64.0	54.5	203 inches long, poor surface, torn edges.
40	H-M35	TZM-7608	3.725	8	2800	AL-30-45	H-DM33	AL-N-56	34:1	--	--	--	--	Press blocked.
41	--	3-36090[3]	3.725	5	2050	AL-26-35	H-DM48	AL-19-56	40.3:1	150	115	40.5	31.1	118 inches long, excellent surface, good corners and fillets.
42	H-M36	TZM-7534	3.725	5	3200	AL-30-45	H-DM49	AL-N-56	42.2:1	219	142	56.4	37.9	108 inches long, poor corners, good fillets, light glass rub-in.

(1) From liner of 3.875-inch diameter

(2) Calculated by $P = K \ln R$ $\begin{cases} P = \text{liner pressure, psi} \\ K = \text{resistance to deformation, psi} \\ R = \text{reduction ratio} \end{cases}$

(3) Stainless steel of 306 Grade

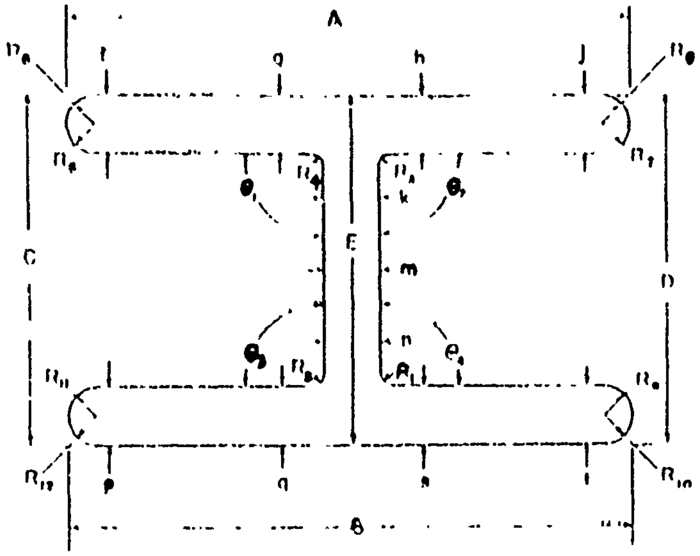


TABLE 3

Dimensional Runout and Die Performance
for Stainless Extrusion No. 27

LOCATION	EXTRUSION FRONT	EXTRUSION BACK	EXTRUSION DIFFERENCE	DIE	DIFFERENCE FROM DIE FRONT	DIFFERENCE FROM DIE BACK
A	1.714	1.713	-.001	1.750	-.036	-.037
B	1.684	1.697	+.013	1.750	-.066	-.053
C	.934	.946	+.012	.996	-.062	-.050
D	.934	.951	+.017	.996	-.062	-.045
E	.973	.970	-.003	.995	-.022	-.025
F	.060	.055	-.005	.061	-.001	-.006
G	.059	.058	-.001	.061	+.002	-.003
H	.058	.057	-.001	.061	-.003	-.003
J	.057	.057	0	.061	-.004	-.004
K	.056	.053	-.003	.057	-.001	-.004
M	.058	.056	-.002	.057	+.001	-.001
N	.057	.053	-.004	.057	0	-.004
P	.051	.053	+.002	.061	-.010	-.008
Q	.059	.058	-.001	.061	-.002	-.003
S	.059	.056	-.003	.061	-.002	-.005
Z	.056	.052	-.004	.062	-.006	-.010
R_1	.032	.036	+.004	.029	+.003	+.007
R_2	.032	.031	-.001	.032	0	-.001
R_3	.032	.033	+.001	.030	+.002	+.003
R_4	.029	.032	+.003	.030	-.001	+.002
R_5	(1)	.029	--	.034	(1)	-.005
R_6	(1)	(1)	--	.033	(1)	(1)
R_7	.031	.029	-.002	.031	0	-.002
R_8	(1)	(1)	--	.031	(1)	(1)
R_9	.032	.031	-.001	033	-.001	-.002
R_{10}	.043	(1)	--	.032	+.011	(1)
R_{11}	.032	.032	0	.032	0	0
R_{12}	.040	(1)	--	.034	+.006	(1)
θ_1	87.1	88.7	+.6	90	-2.9	-1.3
θ_2	88.6	90	+.4	90	-1.4	0
θ_3	88.8	88.1	-.7	90	-1.2	-1.9
θ_4	88.2	89.3	+1.1	90	-1.8	-.7

(1) Too irregular to measure

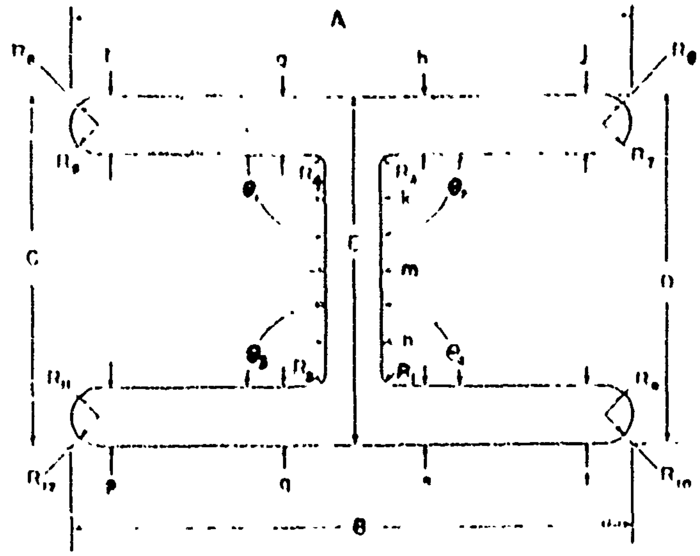


TABLE 4

Dimensional Runout and Die Performance for TZM Extrusion No. 28

LOCATION	EXTRUSION FRONT	EXTRUSION BACK	EXTRUSION DIFFERENCE	DIE	DIFFERENCE FROM DIE FRONT	DIFFERENCE FROM DIE BACK
A	1.7309	1.7275	-.0034	1.750	-.019	-.023
B	1.7324	1.7362	+.0038	1.751	-.019	-.015
C	.9723	.9704	-.0019	.984	-.012	-.014
D	.9561	.9679	+.0118	.997	-.041	-.029
E	.987	1.0052	+.0182	.997	-.010	+.008
F	.0638	.0613	-.0025	.066	-.002	-.005
G	.0675	.0701	+.0026	.066	+.001	+.004
H	.0675	.0708	+.0033	.066	+.001	+.005
J	.0630	.0573	-.0057	.061	+.002	-.004
K	.0648	.0800	+.0152	.064	+.001	+.016
M	.0654	.0807	+.0153	.065	0	+.016
N	.0655	.0802	+.0147	.064	+.001	+.016
P	.0633	.0610	.0023	.062	+.001	-.001
Q	.0657	.0722	+.0065	.067	-.001	+.005
S	.0664	.0712	+.0048	.066	0	+.005
Z	.0638	.0520	-.0118	.066	-.002	-.014
R_1	.029	.077	+.048	.030	-.001	+.047
R_2	.031	.073	+.042	.030	+.001	+.043
R_3	.031	.073	+.042	.032	-.001	+.041
R_4	.030	.084	+.054	.033	-.003	+.030
R_5	.043	NM	--	.033	+.010	(1)
R_6	.030	NM	--	.033	-.003	(1)
R_7	.036	NM	--	.033	+.003	(1)
R_8	.020	NM	--	.030	-.010	(1)
R_9	.030	.030	0	.030	0	0
R_{10}	.021	NM	--	.030	-.009	(1)
R_{11}	.036	NM	--	.035	+.001	(1)
R_{12}	.034	NM	--	.035	-.001	(1)
θ_1	89°22'	87°27'	-1°55'	90	-.6	-2.6
θ_2	89°16'	90°	+44'	89.6	-.3	+.4
θ_3	90°	87°50'	-2°10'	89.7	+.3	-1.9
θ_4	89°50'	87°29'	-2°21'	89.8	0	-2.3

(1) Too irregular to measure

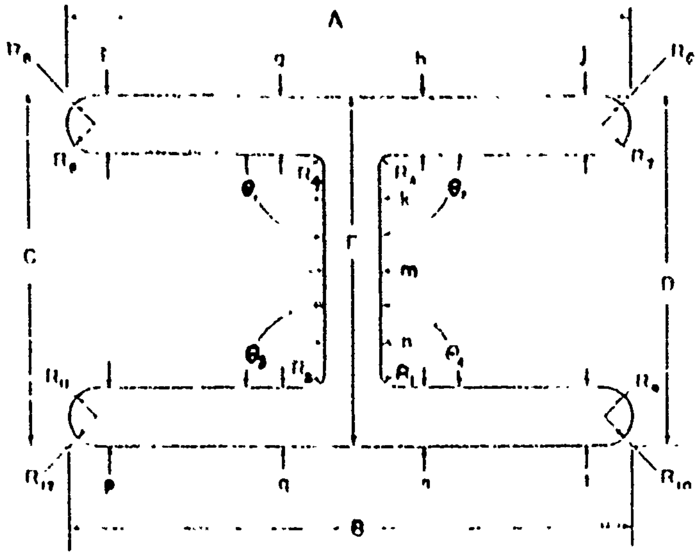


TABLE 5

Dimensional Runout and Die Performance for TZM Extrusion No. 29

LOCATION	EXTRUSION FRONT	EXTRUSION BACK	EXTRUSION DIFFERENCE	DIE	DIFFERENCE FROM DIE FRONT	DIFFERENCE FROM DIE BACK
A	1.728	1.708	-.020	1.749	-.021	-.041
B	1.721	1.726	+.005	1.749	-.028	-.023
C	.959	.977	+.018	.995	-.036	-.018
D	.961	.961	0	.995	-.034	-.034
E	.983	.993	+.010	.994	-.011	-.001
F	.057	.052	-.005	.060	-.003	-.008
G	.060	.061	+.001	.060	0	+.001
H	.060	.060	0	.060	0	0
J	.057	.041	-.016	.060	-.003	-.019
K	.058	.062	+.004	.058	0	+.004
M	.057	.061	+.004	.058	-.001	+.003
N	.057	.061	+.004	.058	-.001	+.003
P	.058	.061	+.003	.061	-.003	0
Q	.061	.065	+.004	.061	0	+.004
S	.061	.063	+.002	.061	0	+.002
Z	.057	.047	+.010	.060	-.003	-.013
R_1	.185	.185	0	.186	-.001	-.001
R_2	.185	.185	0	.186	-.001	-.001
R_3	.182	.180	-.002	.186	-.004	-.006
R_4	.182	.177	-.005	.186	-.004	-.009
R_5	.050	.030	-.020	.031	+.019	-.001
R_6	.030	(1)	--	.031	-.001	(1)
R_7	.033	(1)	--	.031	+.002	(1)
R_8	.038	(1)	--	.031	+.007	(1)
R_9	.033	.041	+.008	.031	+.002	+.010
R_{10}	(1)	(1)	--	.031	(1)	(1)
R_{11}	.040	.019	-.021	.031	+.007	-.012
R_{12}	.040	.033	-.007	.031	+.007	+.002
θ_1	89.4	89.5	+.1	90	-.6	-.5
θ_2	89.6	90.7	+1.1	90	-.4	+.7
θ_3	89.5	90.0	+.5	90	-.5	0
θ_4	89.1	89.7	+.6	90	-.9	-.3

(1) Too irregular to measure

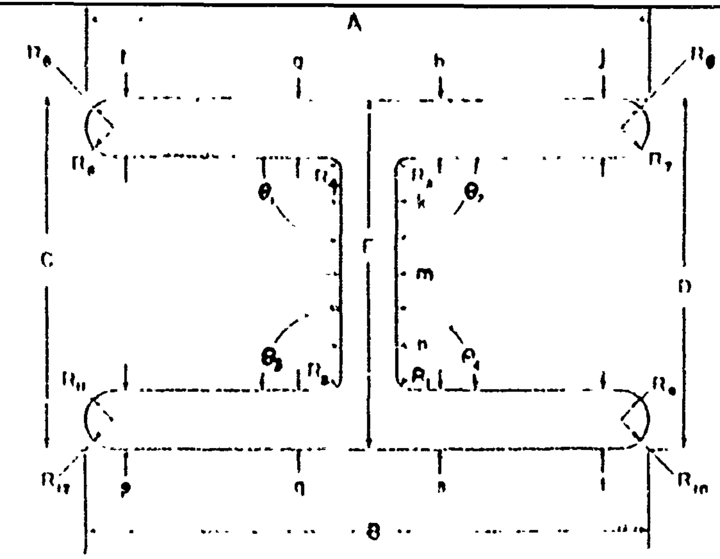


TABLE 6

Dimensional Runout and Die Performance for TZM Extrusion No. 30

LOCATION	EXTRUSION FRONT	EXTRUSION BACK	EXTRUSION DIFFERENCE	DIE	DIFFERENCE FROM DIE FRONT	DIFFERENCE FROM DIE BACK
A	1.743	1.743	0			
B	1.742	1.741	-.001			
C	.985	.981	-.004			
D	.987	.982	-.005			
E	.998	1.003	+.005			
F	.072	.068	-.004			
G	.073	.074	+.001			
H	.074	.075	+.001			
J	.072	.066	-.006			
K	.071	.073	+.002			
M	.071	.075	+.004			
N	.071	.075	+.004			
P	.071	.067	-.004			
Q	.072	.073	+.001			
S	.072	.075	+.003			
Z	.072	.067	-.005			
R_1	.030	.100	+.070			
R_2	.030	.045	+.015			
R_3	.030	.034	+.004			
R_4	.028	.046	+.018			
R_5	.038	.039	+.001			
R_6	.044	.054	+.010			
R_7	.035	(1)	--			
R_8	.041	.060	+.019			
R_9	.040	.045	+.005			
R_{10}	.044	(1)	--			
R_{11}	.038	.032	-.006			
R_{12}	.034	.030	-.004			
θ_1	90.0	89.4	-.6			
θ_2	89.6	89.2	-.4			
θ_3	89.7	89.1	-.6			
θ_4	89.6	89.6	--			

(1) Too irregular to measure

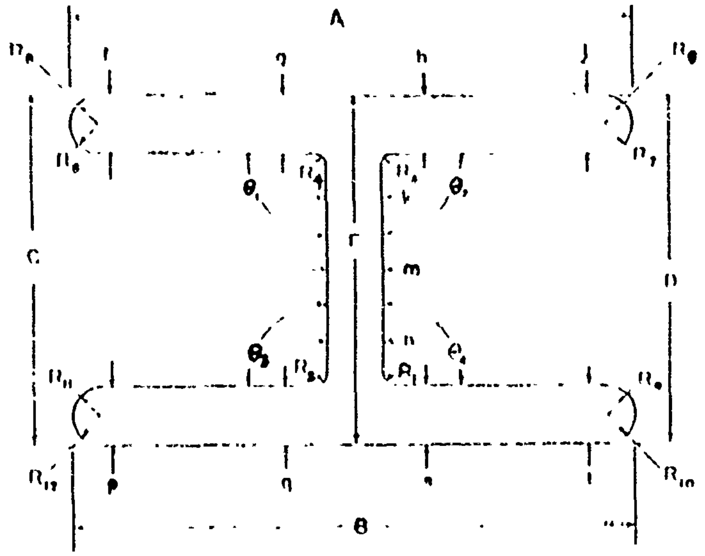


TABLE 7

Dimensional Runout and Die Performance for TZM Extrusion No. 31

LOCATION	EXTRUSION FRONT	EXTRUSION BACK	EXTRUSION DIFFERENCE	DIE	DIFFERENCE FROM DIE FRONT	DIFFERENCE FROM DIE BACK
A	1.724	1.736	+.012			
B	1.723	1.734	+.011			
C	.974	.974	--			
D	.973	.968	-.005			
E	.986	.999	+.013			
F	.065	.061	-.004			
G	.066	.071	+.005			
H	.066	.072	+.006			
J	.063	.067	+.004			
K	.064	.078	+.014			
M	.063	.079	+.016			
N	.064	.075	+.011			
P	.063	.068	+.005			
Q	.065	.070	+.005			
S	.065	.071	+.006			
Z	.063	.064	+.001			
R_1	.028	.083	+.055			
R_2	.030	.053	+.023			
R_3	.029	.077	+.048			
R_4	.029	.081	+.052			
R_5	.035	.028	-.007			
R_6	.038	.040	+.002			
R_7	.030	.031	+.001			
R_8	.023	.060	+.037			
R_9	.033	.032	-.001			
R_{10}	.024	.049	+.025			
R_{11}	.040	.031	-.009			
R_{12}	.027	.040	+.013			
θ_1	89.0	89.0	0			
θ_2	90.2	89.7	-.5			
θ_3	90.4	89.3	-1.1			
θ_4	89.8	89.0	-.8			

(1) Too irregular to measure

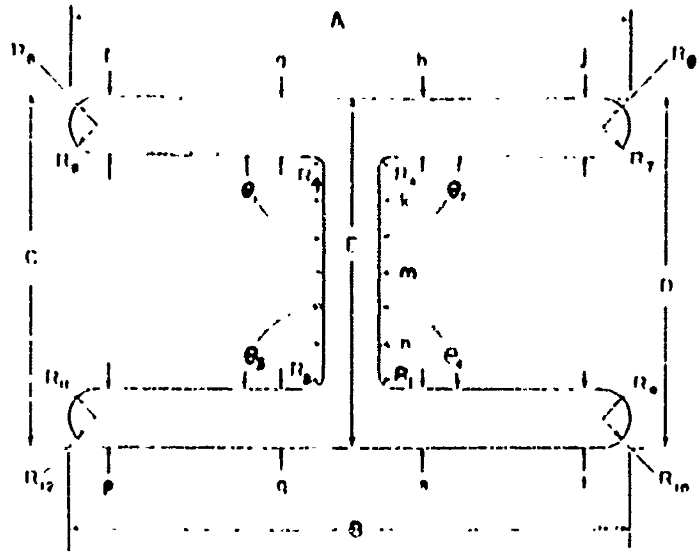


TABLE 8

Dimensional Runout and Die Performance for TZM Extrusion No. 32

LOCATION	EXTRUSION FRONT	EXTRUSION BACK	EXTRUSION DIFFERENCE	DIE	DIFFERENCE FROM DIE FRONT	DIFFERENCE FROM DIE BACK
A	1.712	1.732	+.020	1.752	-.040	-.020
B	1.723	1.743	+.020	1.750	-.027	-.007
C	.949	.960	+.011	.998	-.049	-.038
D	.954	.969	+.015	.997	-.043	-.028
E	.986	1.015	+.029	.997	-.011	+.018
F	.058	.064	+.006	.066	-.008	-.002
G	.063	.067	+.004	.065	-.002	+.002
H	.065	.068	+.003	.066	-.001	+.002
J	.063	.068	+.005	.061	+.002	+.007
K	.064	.080	+.016	.064	0	+.016
M	.064	.098	+.034	.064	0	+.0[illegible]
N	.063	.081	+.018	.064	-.001	+.[illegible]7
P	.057	.068	+.011	.062	-.005	+.006
Q	.065	.073	+.008	.067	-.002	+.006
S	.065	.071	+.006	.066	-.001	+.005
Z	.062	.074	+.012	.066	[illegible].004	+.008
R_1	.031	.050	+.019	.033	-.002	+.017
R_2	.033	.055	+.022	.033	0	+.022
R_3	.036	.056	+.020	.033	+.003	+.023
R_4	.032	.070	+.038	.035	-.003	+.035
R_5	.036	.032	-.004	.035	+.001	-.003
R_6	.050	.030	-.020	.035	+.015	-.005
R_7	.040	.050	+.010	.035	+.005	+.015
R_8	.029	(1)	--	.033	-.004	(1)
R_9	.040	.040	0	.033	+.007	+.007
R_{10}	(1)	.056	--	.033	(1)	+.023
R_{11}	(1)	.040	--	.033	(1)	+.007
R_{12}	(1)	.051	--	.033	(1)	+.018
θ_1	89.4	87.7	-1.7	90°	-.6	-2.7
θ_2	88.9	86.6	-2.3	89.7°	-.8	-3.1
θ_3	39.6	86.9	-2.7	89.8°	-.2	-2.9
θ_4	89.3	86.4	-2.9	89.9°	-.6	-3.5

(1) Too irregular to measure

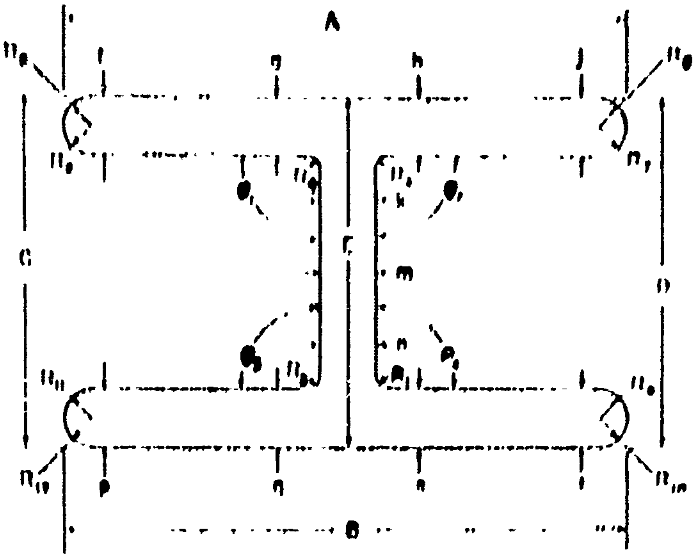


TABLE 9

Dimensional Runout and Die Performance for TZM Extrusion No. 33

LOCATION	EXTRUSION FRONT	EXTRUSION BACK	EXTRUSION DIFFERENCE	DIE	DIFFERENCE FROM DIE FRONT	DIFFERENCE FROM DIE BACK
A	1.740	1.744	+.004	1.752	-.012	-.008
B	1.735	1.744	+.009	1.753	-.018	-.009
C	.972	.973	+.001	.999	-.027	-.026
D	.975	.973	-.002	.999	-.024	-.026
E	.985	.988	+.003	.997	-.012	-.009
F	.064	.062	-.002	.067	-.003	-.005
G	.063	.064	+.001	.066	-.003	-.002
H	.065	.060	+.001	.066	-.001	0
J	.065	.062	-.003	.068	-.003	-.006
K	.063	.068	+.005	.064	-.001	+.004
M	.064	.070	+.006	.064	0	+.006
N	.062	.069	+.007	.064	-.002	+.005
P	.065	.065	0	.068	-.003	-.003
Q	.066	.067	+.001	.068	-.002	-.001
S	.064	.067	+.003	.067	-.003	0
Z	.064	.064	0	.067	-.003	-.003
R_1	.030	.036	+.006	.033	-.003	+.003
R_2	.028	.036	+.008	.034	-.006	+.002
R_3	.033	.037	+.004	.033	0	+.004
R_4	.034	.036	+.002	.034	0	+.002
R_5	.032	.037	+.005	.032	0	+.005
R_6	.043	(1)	--	.030	+.013	(1)
R_7	.034	.029	-.005	.033	+.001	-.004
R_8	.042	.040	-.002	.030	+.012	+.010
R_9	.035	.041	+.006	.034	+.001	+.007
R_{10}	.038	.022	-.016	.034	+.004	-.012
R_{11}	.032	.030	-.002	.033	+.001	-.003
R_{12}	.024	.032	+.008	.032	-.008	0
θ_1	89.5	89.0	-.5	90	-.5	-1.0
θ_2	90.0	89.0	-1.0	89.7	+.3	-.7
θ_3	90.0	88.9	-1.1	90	0	-1.1
θ_4	90.0	89.0	-1.0	90	0	-1.0

(1) Too irregular to measure

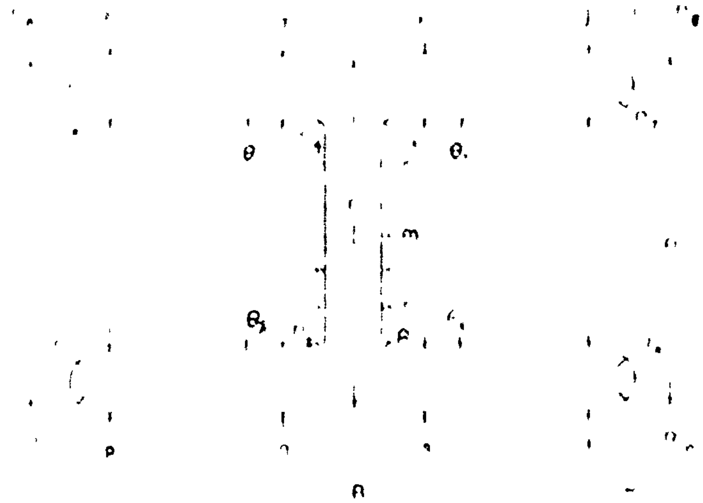


TABLE 10

Dimensional Runout and Die Performance for TZM Extrusion No. 34

LOCATION	EXTRUSION FRONT	EXTRUSION BACK	EXTRUSION DIFFERENCE	DIE	DIFFERENCE FROM DIE FRONT	DIFFERENCE FROM DIE BACK
A	1.740	1.743	+.003			
B	1.735	1.736	+.001			
C	.962	.965	+.003			
D	.976	.978	+.002			
E	.986	.986	0			
F	.064	.063	-.001			
G	.062	.068	+.006			
H	.066	.069	+.003			
J	.065	.073	+.008			
K	.060	.062	+.002			
M	.060	.062	+.002			
N	.060	.061	+.002			
P	.066	.064	-.002			
Q	.066	.068	+.002			
S	.065	.067	+.002			
Z	.064	.068	+.004			
R_1	.034	.060	+.026			
R_2	.037	.057	+.020			
R_3	.032	.056	+.024			
R_4	.032	.060	+.028			
R_5	.031	.034	+.003			
R_6	.035	.045	+.010			
R_7	.031	(1)	--			
R_8	.030	(1)	--			
R_9	.035	.050	+.015			
R_{10}	.035	(1)	--			
R_{11}	.034	.031	-.003			
R_{12}	.039	.033	-.006			
θ_1	90.0	90.0	0			
θ_2	89.5	89.7	+.2			
θ_3	89.1	89.3	+.2			
θ_4	90.4	89.7	+.7			

(1) Too irregular to measure

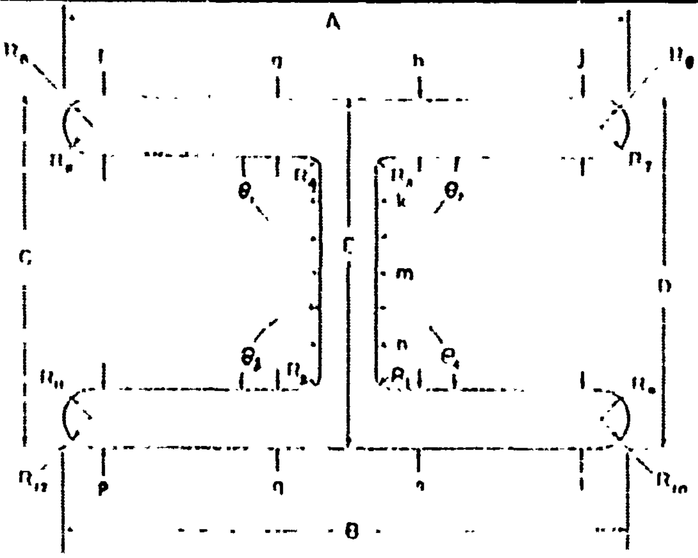


TABLE 11

Dimensional Runout and Die Performance
for TZM Extrusion No. 35

LOCATION	EXTRUSION FRONT	EXTRUSION BACK	EXTRUSION DIFFERENCE	DIE	DIFFERENCE FROM DIE FRONT	DIFFERENCE FROM DIE BACK
A	1.738	1.735	-.003	1.751	-.013	-.016
B	1.739	1.734	-.005	1.752	-.013	-.018
C	.959	.971	+.012	.998	-.039	-.027
D	.978	.968	-.010	.998	-.020	-.030
E	.968	.986	+.018	.998	-.030	-.012
F	.057	.059	+.002	.061	-.004	-.002
G	.060	.060	0	.061	-.001	-.001
H	.061	.060	-.001	.061	0	-.001
J	.058	.059	+.001	.062	-.004	-.003
K	.059	.058	-.001	.059	0	-.001
M	.058	.058	0	.060	-.002	-.002
N	.057	.058	+.001	.059	-.002	-.001
P	.059	.060	+.001	.062	-.003	-.002
Q	.062	.061	-.001	.062	0	-.001
S	.061	.061	0	.062	-.001	-.001
Z	.059	.059	0	.061	-.002	-.002
R_1	.060	.030	-.030	.034	+.026	-.004
R_2	.065	.030	-.035	.032	+.033	-.002
R_3	.070	.027	-.043	.032	+.038	-.005
R_4	.073	.027	-.046	.028	+.045	-.001
R_5	.030	.030	0	.031	-.001	-.001
R_6	.019	.044	+.025	.032	-.013	+.012
R_7	.030	.035	+.005	.032	-.002	+.003
R_8	(1)	.046	--	.031	--	+.015
R_9	.034	.030	-.004	.033	+.001	-.003
R_{10}	(1)	.031	--	.033	--	-.002
R_{11}	.031	.030	-.001	.033	-.002	-.003
R_{12}	.041	.030	-.011	.033	+.008	-.003
θ_1	89.0	89.7	+.7	90.0	-1.0	-.3
θ_2	90.0	90.0	0	90.0	0	0
θ_3	89.7	89.6	-.1	90.0	-.3	-.4
θ_4	90.0	90.0	0	90.0	0	0

(1) Too irregular to measure

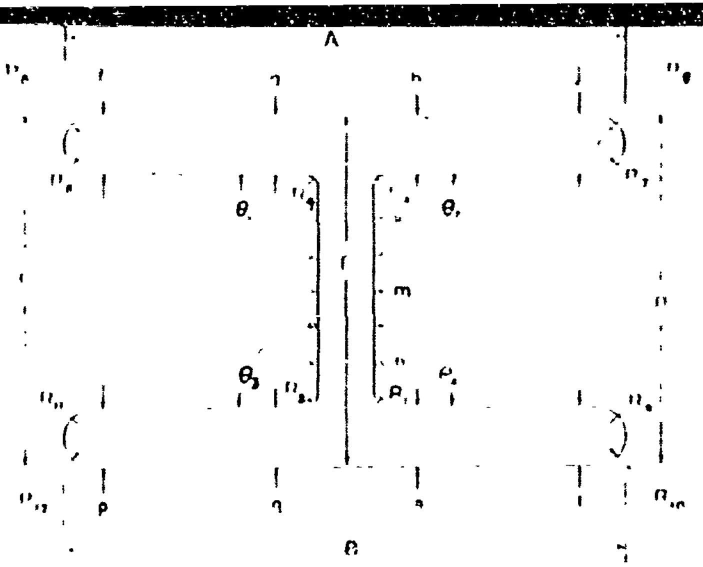


TABLE 12

Dimensional Runout and Die Performance
for TZM Extrusion No. 36

LOCATION	EXTRUSION FRONT	EXTRUSION BACK	EXTRUSION DIFFERENCE	DIE	DIFFERENCE FROM DIE FRONT	DIFFERENCE FROM DIE BACK
A	1.735	1.739	+.004			
B	1.731	1.734	+.003			
C	.962	.966	+.004			
D	.971	.972	+.001			
E	.986	.987	+.001			
F	.060	.059	-.001			
G	.062	.064	+.002			
H	.062	.063	+.001			
J	.062	.059	-.003			
K	.057	.058	+.001			
M	.057	.059	+.002			
N	.059	.059	0			
P	.060	.053	-.007			
Q	.061	.061	0			
S	.061	.061	0			
Z	.060	.059	-.001			
R_1	.052	.057	+.005			
R_2	.057	.053	-.004			
R_3	.055	.063	+.008			
R_4	.053	.050	-.003			
R_5	.031	.030	-.001			
R_6	.030	.056	+.026			
R_7	.031	.034	+.003			
R_8	.028	(1)	--			
R_9	.031	.041	+.010			
R_{10}	.034	.061	+.027			
R_{11}	.039	.033	-.006			
R_{12}	.037	(1)	--			
θ_1	89.7	90.0	+.3			
θ_2	89.7	89.2	-.5			
θ_3	89.4	89.5	+.1			
θ_4	90.0	89.5	-.5			

(1) Too irregular to measure

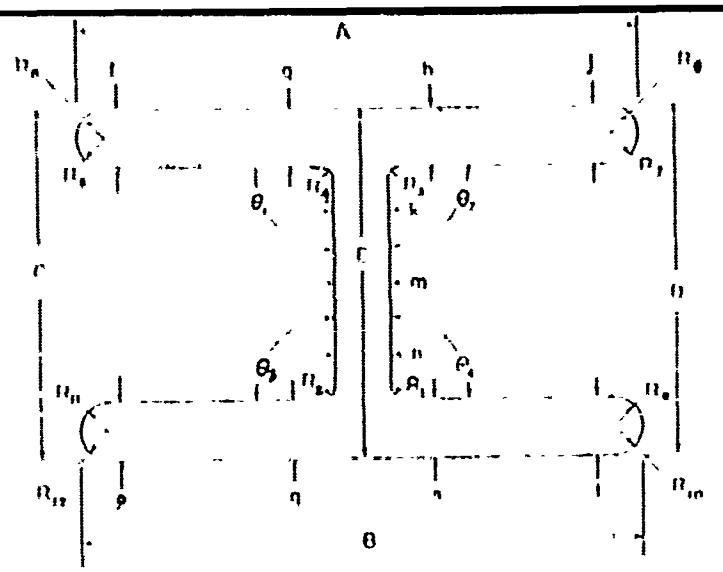


TABLE 13

Dimensional Runout and Die Performance
for TZM Extrusion No. 37

LOCATION	EXTRUSION FRONT	EXTRUSION BACK	EXTRUSION DIFFERENCE	DIE	DIFFERENCE FROM DIE FRONT	DIFFERENCE FROM DIE BACK
A	1.733	1.729	-.004	1.752	-.019	-.023
B	1.727	1.727	0	1.752	-.025	-.025
C	.973	.975	+.002	.999	-.026	-.024
D	.972	.973	+.001	.999	-.027	-.026
E	.984	.987	+.003	.998	-.014	-.011
F	.060	.064	+.004	.061	-.001	+.003
G	.061	.066	+.005	.062	-.001	+.004
H	.061	.063	+.002	.061	0	+.002
J	.059	.059	0	.061	-.002	-.002
K	.056	.062	+.006	.059	-.003	+.003
M	.057	.064	+.007	.060	-.003	+.004
N	.056	.063	+.007	.060	-.004	+.003
P	.059	.062	+.003	.061	-.002	+.001
Q	.060	.065	+.005	.060	0	+.005
S	.061	.063	+.002	.062	-.001	+.001
Z	.059	.057	-.002	.061	-.002	-.004
R_1	.031	.088	+.057	.030	+.001	+.058
R_2	.031	.074	+.043	.030	+.001	+.044
R_3	.035	.070	+.035	.035	0	+.035
R_4	.035	.071	+.036	.033	+.002	+.038
R_5	.034	(1)	--	.035	-.001	--
R_6	.033	(1)	--	.035	-.002	--
R_7	.030	(1)	--	.035	-.005	--
R_8	.029	(1)	--	.035	-.006	--
R_9	.032	.040	+.008	.035	-.003	+.005
R_{10}	.030	(1)	--	.035	-.005	--
R_{11}	.032	(1)	--	.035	-.003	--
R_{12}	.041	(1)	--	.035	+.006	--
θ_1	88.7	90.0	+1.3	90.0	-1.3	0
θ_2	89.6	89.2	-.4	90.0	-.4	-.8
θ_3	88.5	88.8	+.3	90.0	-1.5	-1.2
θ_4	90.8	90.0	-.8	90.0	+.8	0

(1) Too irregular to measure

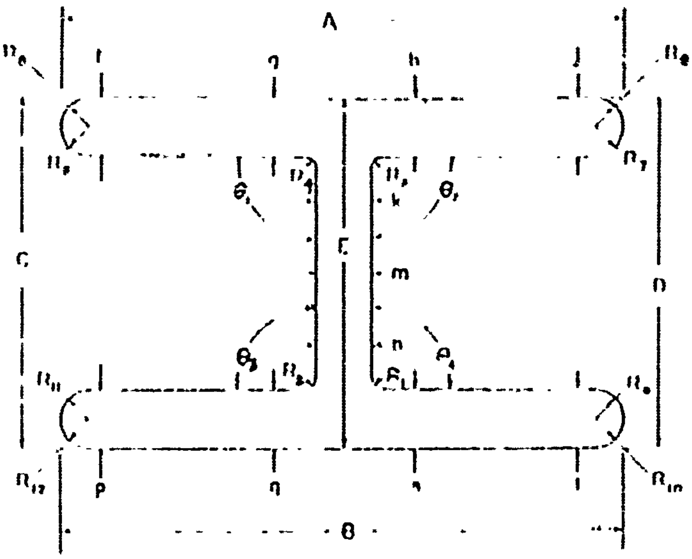


TABLE 14

Dimensional Runout and Die Performance for TZM Extrusion No. 38

LOCATION	EXTRUSION FRONT	EXTRUSION BACK	EXTRUSION DIFFERENCE	DIE	DIFFERENCE FROM DIE FRONT	DIFFERENCE FROM DIE BACK
A	1.741	1.752	+.011	1.762	-.021	-.011
B	1.740	1.753	+.013	1.763	-.023	-.013
C	.957	.974	+.013	1.008	-.051	-.034
D	.975	.974	-.001	1.008	-.033	-.034
E	.992	1.011	+.019	1.007	-.015	+.004
F	.068	.085	+.017	.072	-.004	+.013
G	.070	.078	+.008	.072	-.002	+.006
H	.069	.080	+.011	.071	-.002	+.009
J	.070	.081	+.011	.071	-.001	+.010
K	.066	.073	+.007	.070	-.004	+.003
M	.067	.086	+.019	.069	-.002	+.017
N	.066	.074	+.008	.067	-.001	+.007
P	.070	.082	+.012	.071	-.001	+.011
Q	.071	.089	+.018	.072	-.001	+.017
S	.071	.083	+.012	.072	-.001	+.011
Z	.070	.076	+.006	.071	-.001	+.005
R_1	.034	.049	+.015	.032	+.002	+.017
R_2	.038	.047	+.009	.033	+.005	+.014
R_3	.029	.047	+.018	.029	0	+.018
R_4	.027	.044	+.017	.026	+.001	+.018
R_5	.039	.091	+.052	.038	+.001	+.053
R_6	.034	(1)	--	.036	-.002	--
R_7	.035	.055	+.020	.037	-.002	+.018
R_8	.036	(1)	--	.034	+.002	--
R_9	.038	.042	+.004	.039	-.001	+.003
R_{10}	.032	.043	+.011	.035	-.003	+.008
R_{11}	.039	(1)	--	.034	+.005	--
R_{12}	.037	(1)	--	.035	+.002	--
θ_1	89.5	86.0	+3.5	90.0	-.5	-4.0
θ_2	89.0	87.2	-1.8	90.0	-1.0	-2.8
θ_3	88.4	87.5	-.9	90.0	-1.6	-2.5
θ_4	90.0	86.0	-4.0	90.0	0	-4.0

(1) Too irregular to measure

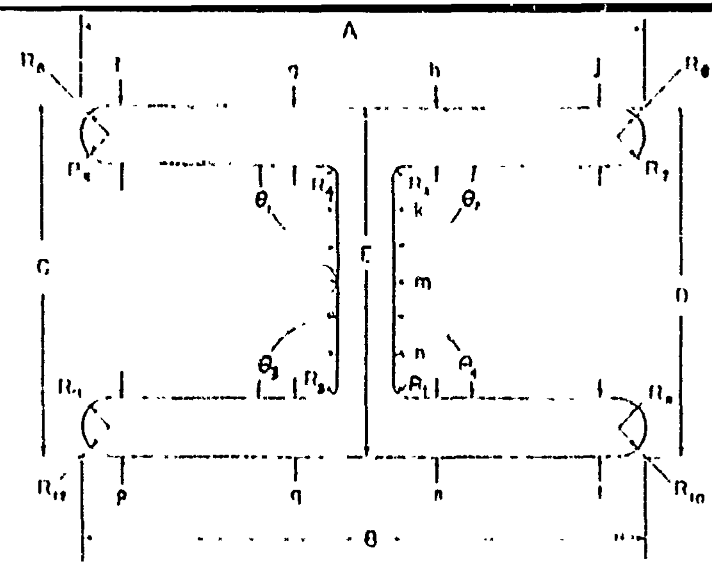
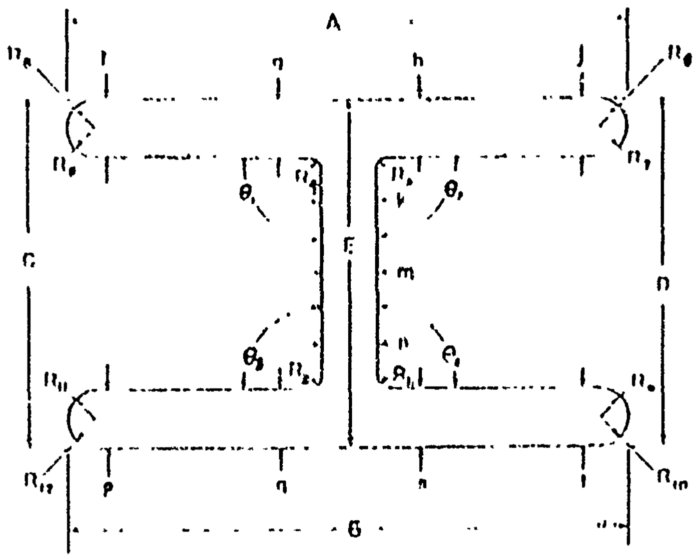


TABLE 15

Dimensional Runout and Die Performance for TZM Extrusion No. 39

LOCATION	EXTRUSION FRONT	EXTRUSION BACK	EXTRUSION DIFFERENCE	DIE	DIFFERENCE FROM DIE FRONT	DIFFERENCE FROM DIE BACK
A	1.727	1.750	+.023	1.748	-.021	+.002
B	1.727	1.740	+.013	1.750	-.021	-.010
C	.966	.970	+.004	1.001	-.035	-.031
D	.970	.970	0	1.001	-.031	-.031
E	.985	1.010	+.025	1.001	-.016	+.009
F	.075	.087	+.012	.078	-.003	+.009
G	.077	.090	+.013	.078	-.001	+.012
H	.077	.088	+.011	.078	-.001	+.010
J	.076	(1)	--	.078	-.002	--
K	.072	.081	+.009	.076	-.004	+.005
M	.072	.109	+.037	.076	-.004	+.033
N	.072	.088	+.016	.076	-.004	+.01[illegible]
P	.076	(1)	--	.078	-.002	--
Q	.077	.094	+.017	.079	-.002	+.015
S	.077	.095	+.018	.078	-.001	+.017
Z	.075	.087	+.012	.078	-.003	+.009
R_1	.032	.070	+.038	.029	+.003	+.041
R_2	.030	.034	+.004	.029	+.001	+.005
R_3	.029	.051	+.022	.026	+.003	+.025
R_4	.029	.054	+.025	.030	-.001	+.024
R_5	.038	(1)	--	.029	+.009	--
R_6	.032	(1)	--	.030	+.002	--
R_7	.043	(1)	--	.030	+.013	--
R_8	.055	.050	-.005	.029	+.026	+.021
R_9	.039	.040	+.001	.029	+.010	+.011
R_{10}	.031	(1)	--	.030	+.001	--
R_{11}	.029	.050	+.021	.032	-.003	+.018
R_{12}	.037	(1)	--	.029		
θ_1	89.7	82.0	-7.7	90.0	-.3	-8.0
θ_2	89.4	85.0	-4.4	90.0	-.6	-5.0
θ_3	89.4	88.7	-.7	90.0	-.6	-1.3
θ_4	89.8	89.0	-.8	90.0	-.2	-1.0

(1) Too irregular to measure



<u>TABLE 16</u>

Dimensional Runout and Die Performance
<u>for TZM Extrusion No. 40</u>

LOCATION	EXTRUSION FRONT	EXTRUSION BACK	EXTRUSION DIFFERENCE	DIE	DIFFERENCE FROM DIE FRONT	DIFFERENCE FROM DIE BACK
A	1.762	1.764	+.002	1.774	-.012	-.010
B	1.758	1.760	+.002	1.773	-.015	-.013
C	.984	1.005	+.021	1.018	-.034	-.013
D	.991	1.009	+.018	1.018	-.027	-.009
E	1.006	1.010	+.004	1.017	-.011	-.007
F	.082	.083	+.001	.083	-.001	0
G	.083	.084	+.001	.082	+.001	+.002
H	.083	.085	+.002	.082	+.001	+.003
J	.082	.085	+.003	.082	0	+.003
K	.075	.076	+.001	.079	-.004	-.003
M	.076	.077	+.001	.080	-.004	-.003
N	.074	.076	+.002	.079	-.005	-.003
P	.080	.081	+.001	.082	-.002	-.001
Q	.081	.082	+.001	.081	0	+.001
S	.080	.082	+.002	.081	-.001	+.001
Z	.080	.081	+.001	.082	-.002	-.001
R_1	.035	.038	+.003	.033	+.002	+.005
R_2	.032	.040	+.008	.033	-.001	+.007
R_3	.031	.038	+.007	.030	+.001	+.008
R_4	.030	.037	+.007	.030	0	+.007
R_5	.046	.045	-.001	.045	+.001	0
R_6	.050	.042	-.008	.045	+.005	-.003
R_7	.043	.042	-.001	.040	+.003	+.002
R_8	.040	.040	0	.040	0	0
R_9	.046	.047	+.001	.045	+.001	+.002
R_{10}	.042	.055	+.013	.040	+.002	+.015
R_{11}	(1)	.050	--	.043	--	+.007
R_{12}	.055	.054	-.001	.043	+.012	+.011
θ_1	89.9	90.0	+.1	90.0	-.1	0
θ_2	89.5	90.0	+.5	90.0	-.5	0
θ_3	89.5	89.4	-.1	90.0	-.5	-.6
θ_4	89.9	89.7	-.2	90.0	-.1	-.3

(1) Too irregular to measure

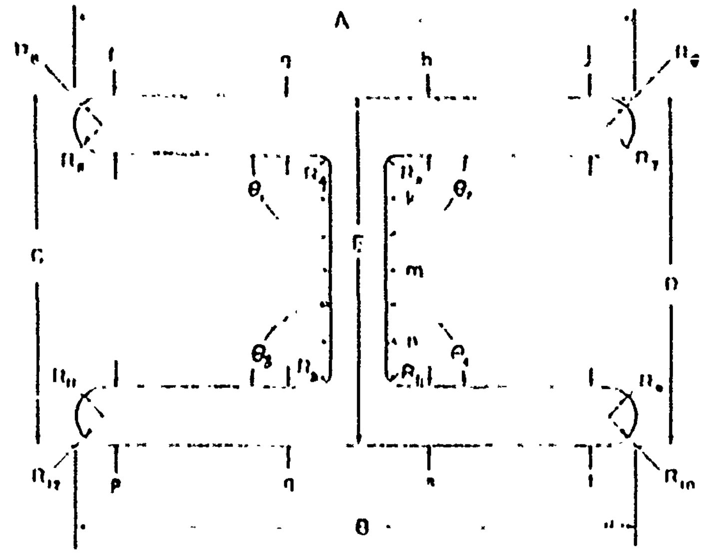


TABLE 17

Dimensional Runout and Die Performance for Stainless Extrusion Number 41

LOCATION	EXTRUSION FRONT	EXTRUSION BACK	EXTRUSION DIFFERENCE	DIE	DIFFERENCE FROM DIE FRONT	DIFFERENCE FROM DIE BACK
A	1.712	1.721	+.009	1.773	-.061	-.052
B	1.713	1.724	+.011	1.775	-.062	-.051
C	.955	.979	+.024	1.018	-.063	-.021
D	.975	.996	+.021	1.017	-.042	-.021
E	.993	.989	-.004	1.017	-.024	-.028
F	.057	.059	+.002	.066	-.009	-.007
G	.062	.059	-.003	.067	-.005	-.008
H	.061	.060	-.001	.067	-.006	-.007
J	.055	.059	+.004	.066	-.011	-.007
K	.069	.066	-.003	.067	+.002	-.001
M	.069	.067	-.002	.067	+.002	0
N	.069	.067	-.002	.068	+.001	-.001
P	.053	.059	+.006	.063	-.010	-.004
Q	.059	.060	+.001	.067	-.008	-.007
S	.062	.061	-.001	.06	+.005	-.006
Z	.058	.060	+.002	.064	+.006	-.004
R_1	.031	.032	+.001	.030	+.001	+.002
R_2	.029	.032	+.003	.030	-.001	+.002
R_3	.030	.032	+.002	.030	0	+.002
R_4	.032	.032	0	.032	0	0
R_5	.029	.028	-.001	.032	-.003	-.004
R_6	(1)	.020		.030		-.010
R_7	.030	.032	+.002	.032	-.002	0
R_8	(1)	.031		.031		0
R_9	.031	.031	0	.032	-.001	-.001
R_{10}	.031	.031	0	.030	+.001	+.001
R_{11}	(1)	.029		.032		-.003
R_{12}	(1)	.030		.032		-.002
θ_1	90.8	89.7	-1.1	90.7	+.1	-1.0
θ_2	88.8	89.5	+.7	89.7	-.9	-.2
θ_3	88.5	89.3	+.8	89.7	-1.2	-.4
θ_4	90	91.3	+1.3	90.7	-.7	+.6

(1) Too irregular to measure

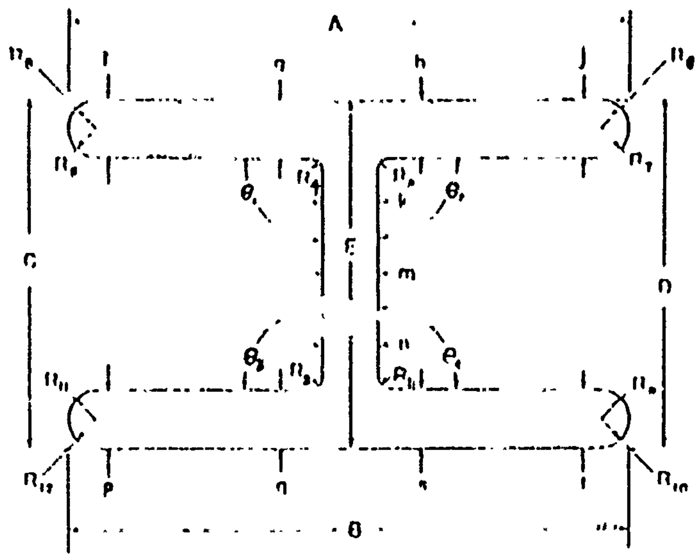


TABLE 18

Dimensional Runout and Die Performance for TZM Extrusion No. 42

LOCATION	EXTRUSION FRONT	EXTRUSION BACK	EXTRUSION DIFFERENCE	DIE	DIFFERENCE FROM DIE FRONT	DIFFERENCE FROM DIE BACK
A	1.740	1.716	-.024	1.776	-.036	-.060
B	1.783	1.746	-.037	1.775	+.008	-.029
C	.996	.982	-.014	1.020	-.024	-.038
D	.995	1.002	+.007	1.018	-.023	-.016
E	1.000	1.006	+.006	1.018	-.018	-.012
F	.059	.053	-.006	.066	-.007	-.013
G	.063	.063	0	.067	-.004	-.004
H	.063	.064	+.001	.067	-.004	-.003
J	.059	.056	-.003	.063	-.004	-.007
K	.067	.071	+.004	.067	0	+.004
M	.067	.076	+.009	.067	0	+.009
N	.065	.070	+.005	.067	-.002	+.003
P	.060	.061	+.001	.062	-.002	-.001
Q	.065	.065	0	.063	+.002	+.002
S	.063	.064	+.001	.063	0	+.001
Z	.060	.060	0	.063	-.003	-.003
R_1	.031	.031	0	.032	-.001	-.001
R_2	.033	.032	-.001	.030	+.003	+.002
R_3	.031	.032	+.001	.030	+.001	+.002
R_4	.032	.032	0	.030	+.002	+.002
R_5	.030	(1)		.033	-.003	(1)
R_6	.040	(1)		.030	+.010	(1)
R_7	.027	.022	-.005	.031	-.004	-.009
R_8	(1)	(1)		.031	(1)	(1)
R_9	(1)	.024		.032	(1)	-.008
R_{10}	(1)	.034		.031	(1)	+.003
R_{11}	.030	.030	0	.030	0	0
R_{12}	(1)	(1)		.031	(1)	(1)
θ_1	91	90	-1.0	90.1	+.9	-.1
θ_2	90	89.1	-.9	89.5	+.5	-.4
θ_3	89.5	88.3	-1.2	90	-.5	-1.7
θ_4	91.2	90.5	-.7	89.5	+1.7	+1.0

(1) Too irregular to measure

These extrusions were exploratory in nature and were made primarily to determine the influence of die design on liner pressure and extrusion dimensional runout.

Extrusion No. 28 with Die H-DM27 and Extrusion No. 29 with Die H-DM25 were made to determine the affect on liner pressure by a variation in fillet radii of 1/32 inch and 3/16 inch. Other die design features such as nominal 0.062-inch web opening and 20 degree basic angle were the same for both dies. Extrusion No. 29 with a fillet radius of 3/16-inch required little more liner pressure than Extrusion No. 28 with 1/32-inch fillet radius. Dimensional checks given in Tables 4 and 5 were better for Extrusion No. 29 having a larger fillet radius.

Examination of the dies after extrusion revealed severe die metal flow in the fillet radii in both dies.

Extrusion No. 30 with Die H-DM28 having 1/32-inch fillet radius, nominal 0.070-inch web opening and 20 degree basic angle did not alter significantly the pressure required for extrusion. Dimensional runout for this extrusion was very good except in the fillet radii (Table 6). Again severe die metal flow occurred in the fillet radii.

Extrusion No. 31 with Die H-DM35 having 1/32-inch fillet radius, nominal 0.062-inch web openeing and 30 degree basic angle did not alter peak liner pressure as required for previous extrusions with 20 degree basic angle dies. Run liner pressure, however, was somewhat less and the press seemed to accomplish the extrusion with less effort. Die H-DM35 also revealed die metal flow in the fillet radii. Dimensional runout, Table 7, was not good for this extrusion.

Extrusion conditions for Extrusion No. 31 were the same for Extrusion No. 32. Good dimensional runout, Table 8, was found in the extrusion except in the stem section which experienced coating failure. No die metal flow was found in the fillet radii.

Entry radii pattern for Die H-DM39 used in Extrusion No. 33 was not the same as that in previously used dies. This design is shown in Figure 7. Dimensional runout was very good as shown in Table 9. This die is being prepared for reuse.

Extrusions No. 34 through No. 36 were accomplished with powder metallurgy TZM billets. Good response to extrusion was displayed by this material which was extruded to nominal 0.062-inch web thickness from a low temperature of 2800F. Dimensional runout for these extrusions are given in Tables 10 to 12. Evaluation of these extrusions is given in the Appendix to this report.

Extrusions Nos. 37 and 38 made with similar die design but at 3200F and 3350F billet temperatures, respectively, revealed very poor coating performance at the higher billet temperature. Considerably less run pressure at the higher temperature was also observed although the peak pressures were similar.

TZM in the stress relieved condition was used for Extrusions Nos. 39 and 40. Extrusion No. 39 from 3200F billet temperature was poor and Extrusion No. 40 from 2800F blocked the press. No additional extrusions will be made with this material.

Solid zirconia H-shaped dies were used for the first time in this program. Extrusion No. 41 with 304 Stainless steel was accomplished from 2100F with excellent results. Dimensional runout is shown in Table 17. It was apparent that this die material without ductility can be supported adequately for extrusion purposes. TZM Extrusion No. 42 from 3200F was then made and similar good results were obtained (Table 18). Furthermore, this extrusion required lower liner pressure than that for previous extrusions with segmented and coated dies. This lower observed pressure was due in part by the absence of segmented interfaces which are a source of weakness and erosion and by the material's inherent resistance to wear.

In general, the extrusion of TZM to 0.062-inch web thickness and 1/32-inch fillet radius was accomplished within available liner capacity of 237,000 psi without support tooling failure. Billet temperature for this purpose was 3200F and there is a possibility this can be lower. Die performance with segmented and coated tool steel dies was not consistent. On the other hand, die "wash" and severe corner "flash" did not occur. A few segmented, coated dies, regardless of design and material, experienced metal flow (not wash) beneath the coating at the fillet radius and may be the cause for changes in fillet radius size. Die design having a 30 degree basic angle rather than 20 degree was more favorable at least in lowering pressures required for extrusion. Lastly, the promising performance of solid zirconia H-shaped dies was demonstrated, particularly by the high resistance to wear and erosion under extrusion conditions.

D. Extrusion Evaluation

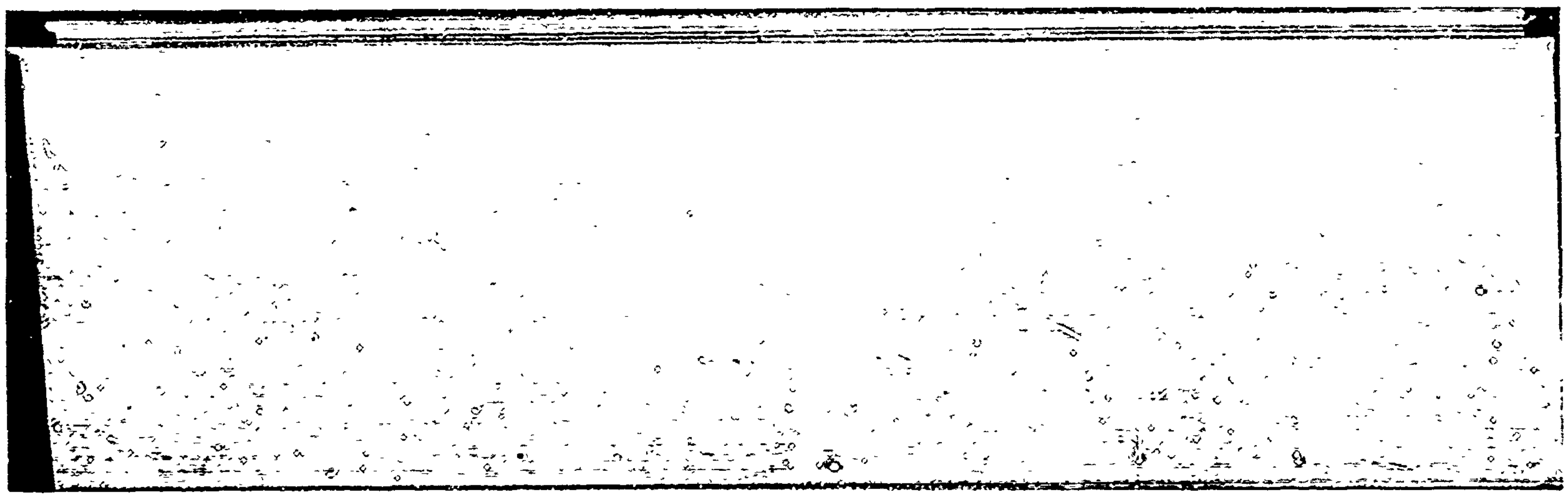
1. Physical Characteristics

As-extruded surface quality of H-shaped extrusions of TZM are shown in Figures 9 through 21. Remarks on surface quality and extrusion lengths are given in Table 2. Surface RMS readings are summarized in Table 19.

Surface quality of these extrusions was not a matter of primary concern at this point in the program. Changes in billet structure and die design along with lubrication studies already underway should lower RMS surface values. Results thus far do indicate that the goal of 50 RMS can be achieved. It was apparent too that surface quality was consistent and remarkably good for Extrusion No. 42 produced with a solid zirconia die which was not polished or given any finishing after sintering.

Visual examination of the corners were summarized as follows:

Back-End View
Magnification: 1X

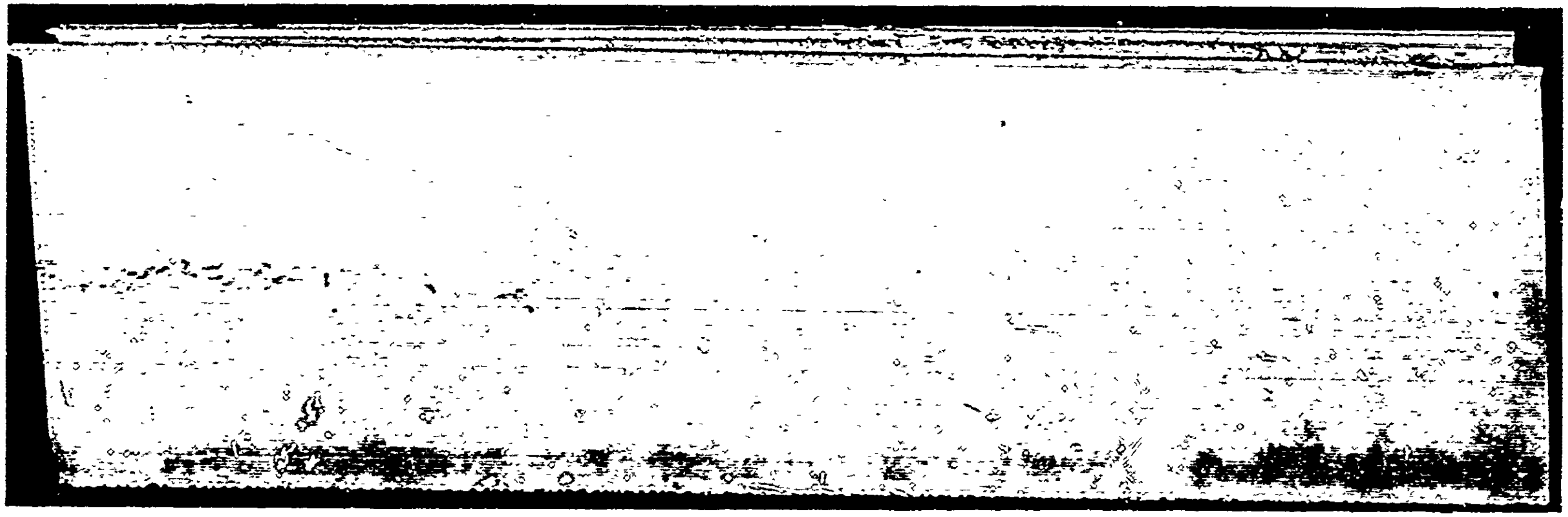


Back-Side View
Magnification: 1-1/4X

FIGURE 9

As-Extruded Surface After Sandblasting of TZM Extrusion No. 28

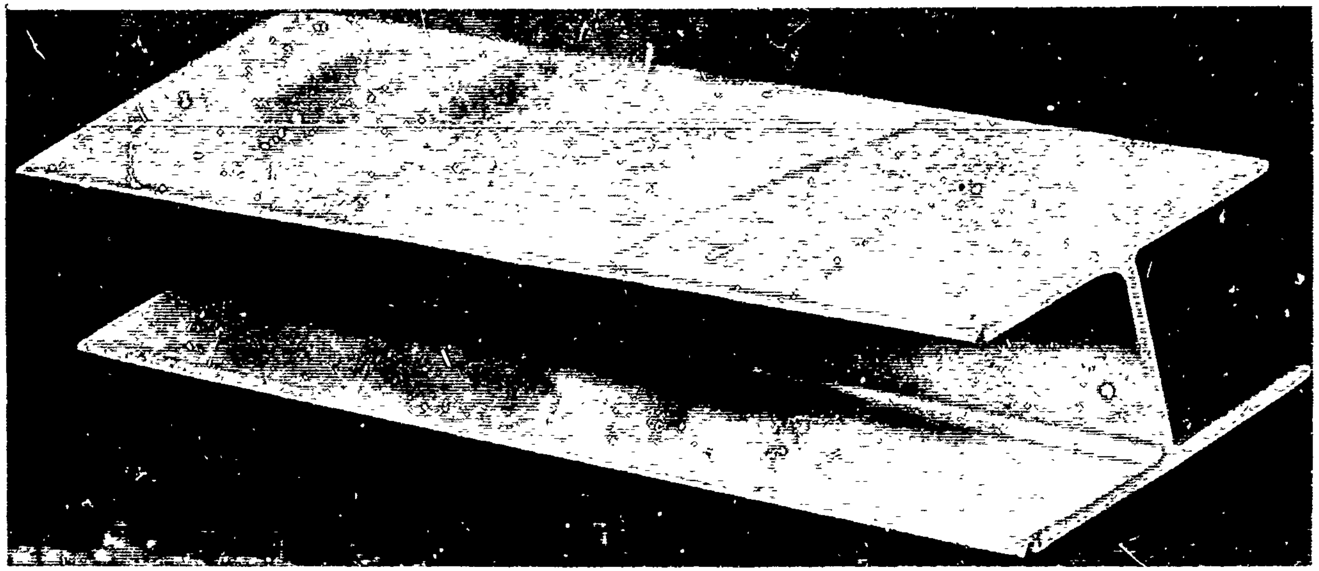
Back-End View
Magnification: 1X



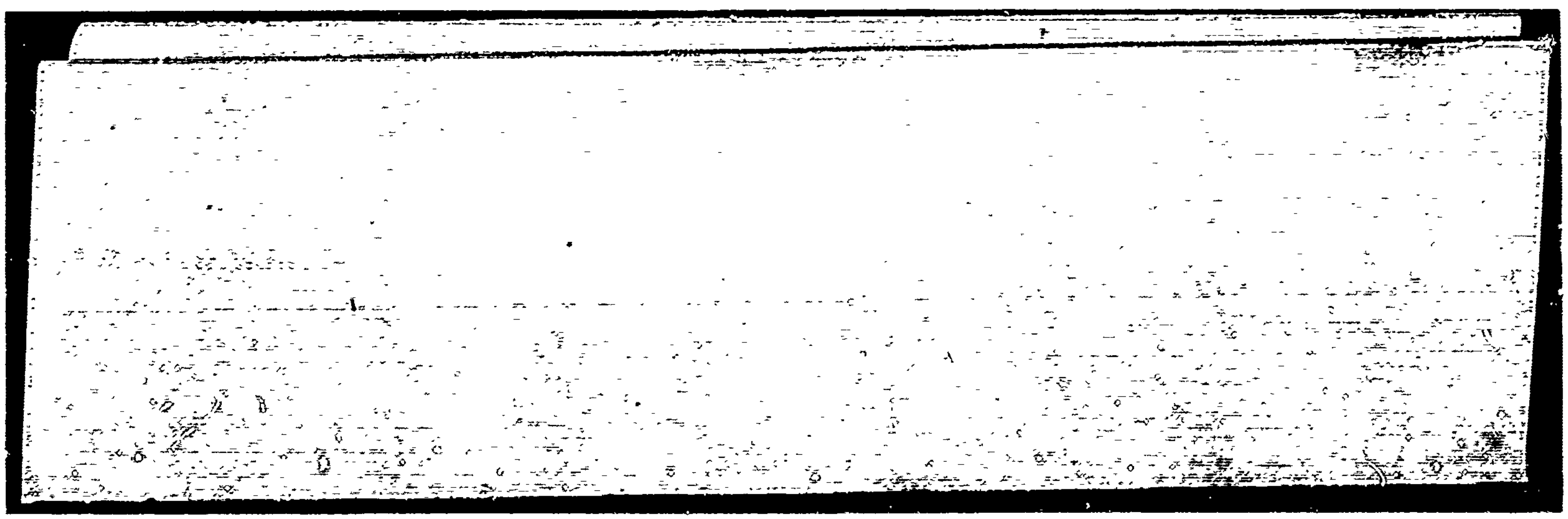
Back-Side View
Magnification: 1-1/4X

FIGURE 10

As-Extruded Surface After Sandblasting of TZM Extrusion No. 29



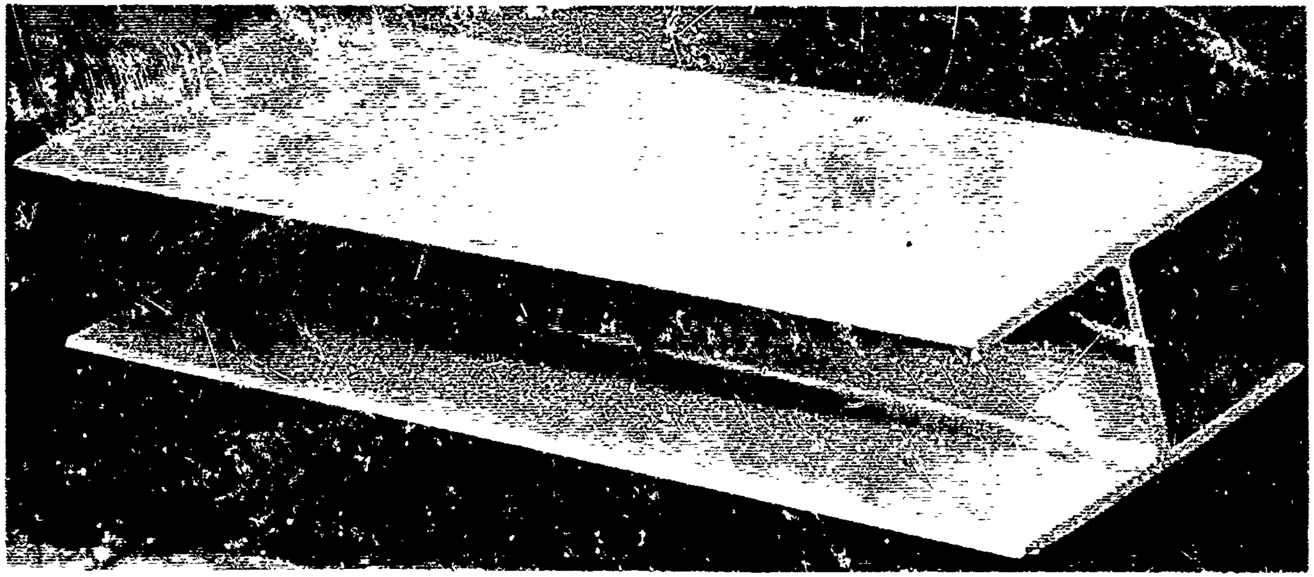
Back-End View
Magnification: 1X



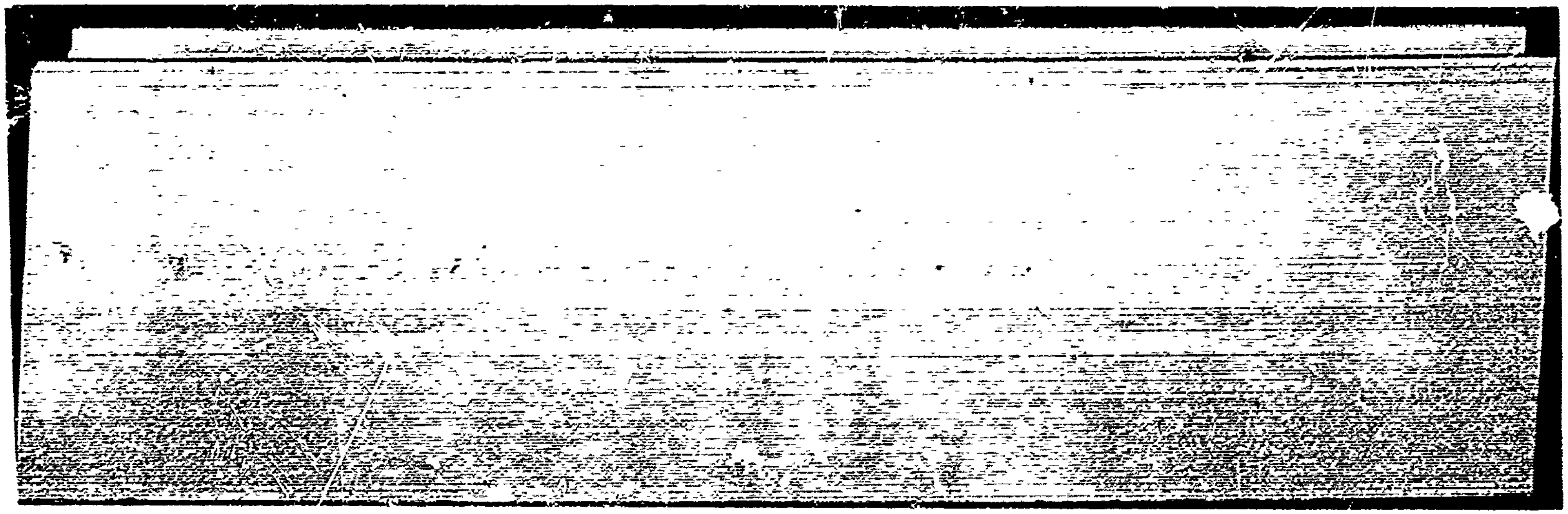
Back-Side View
Magnification: 1-1/4X

FIGURE 11

As-Extruded Surface After Sandblasting of TZM Extrusion No. 30



Back-End View
Magnification: 1X

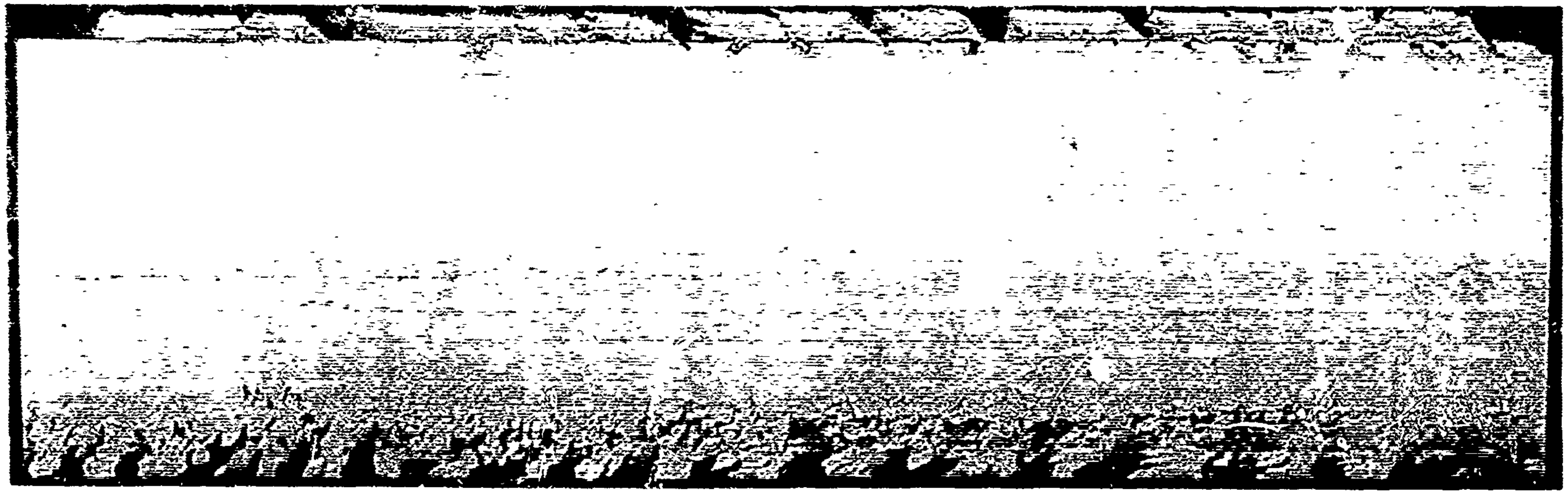


Back-Side View
Magnification: 1-1/4X

FIGURE 12

As-Extruded Surface After Sandblasting of TZM Extrusion No. 31

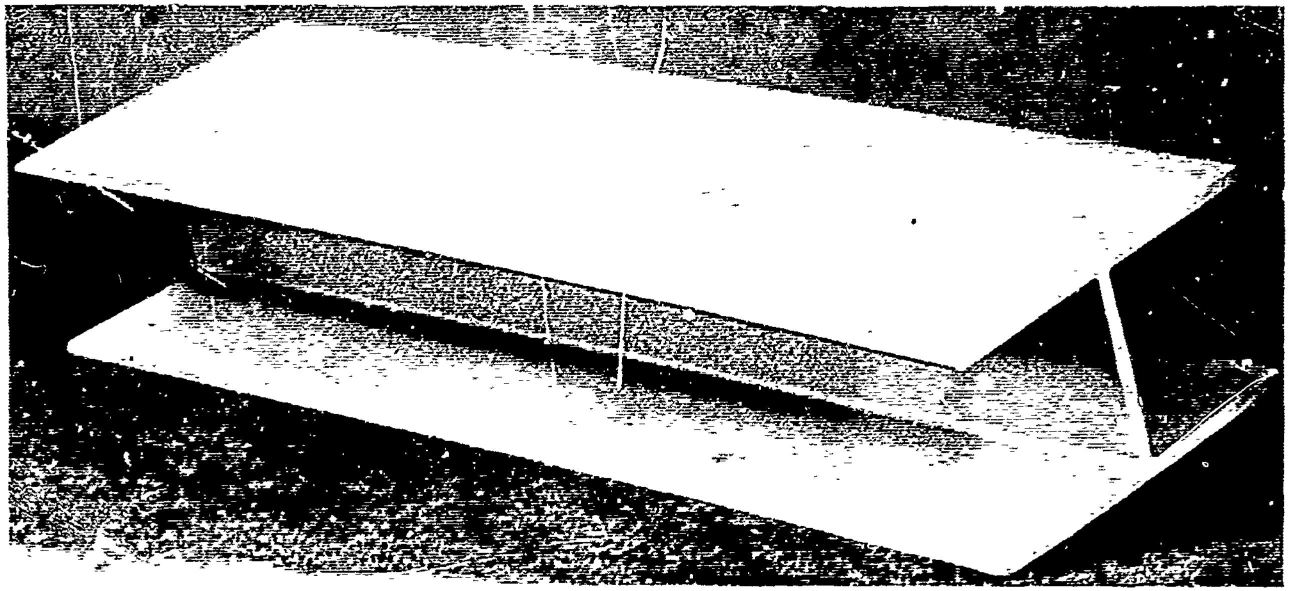
Back-End View
Magnification: 1X



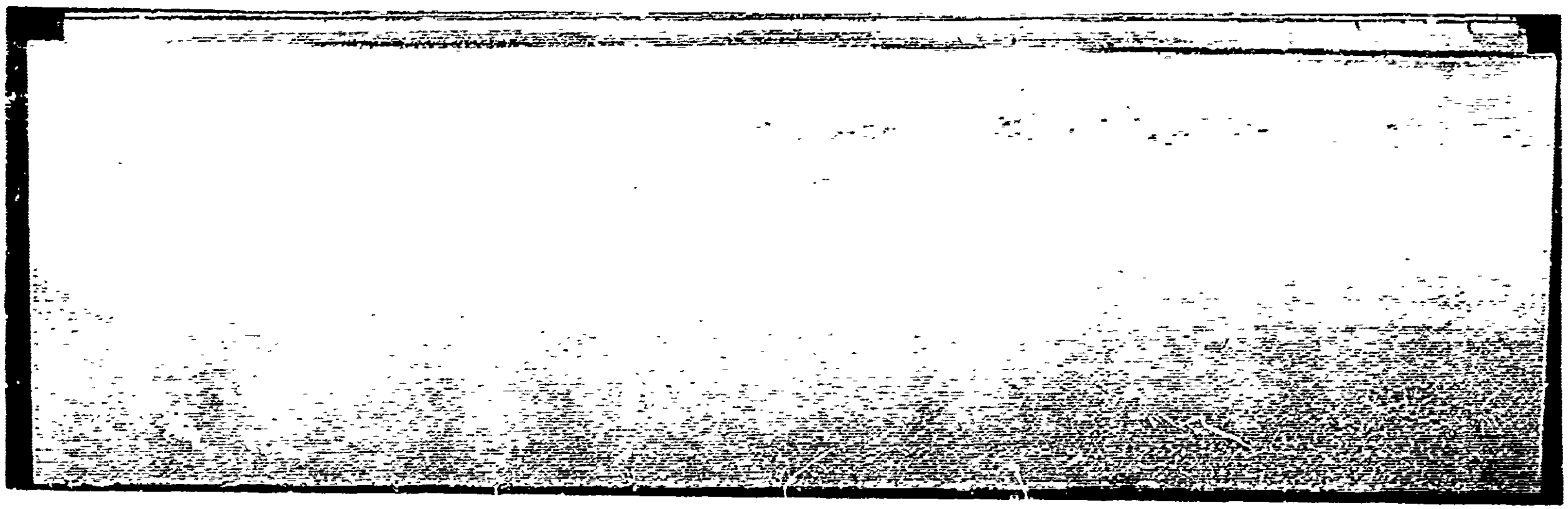
Back-Side View
Magnification: 1-1/4X

FIGURE 13

As-Extruded Surface After Sandblasting of TZM Extrusion No. 32



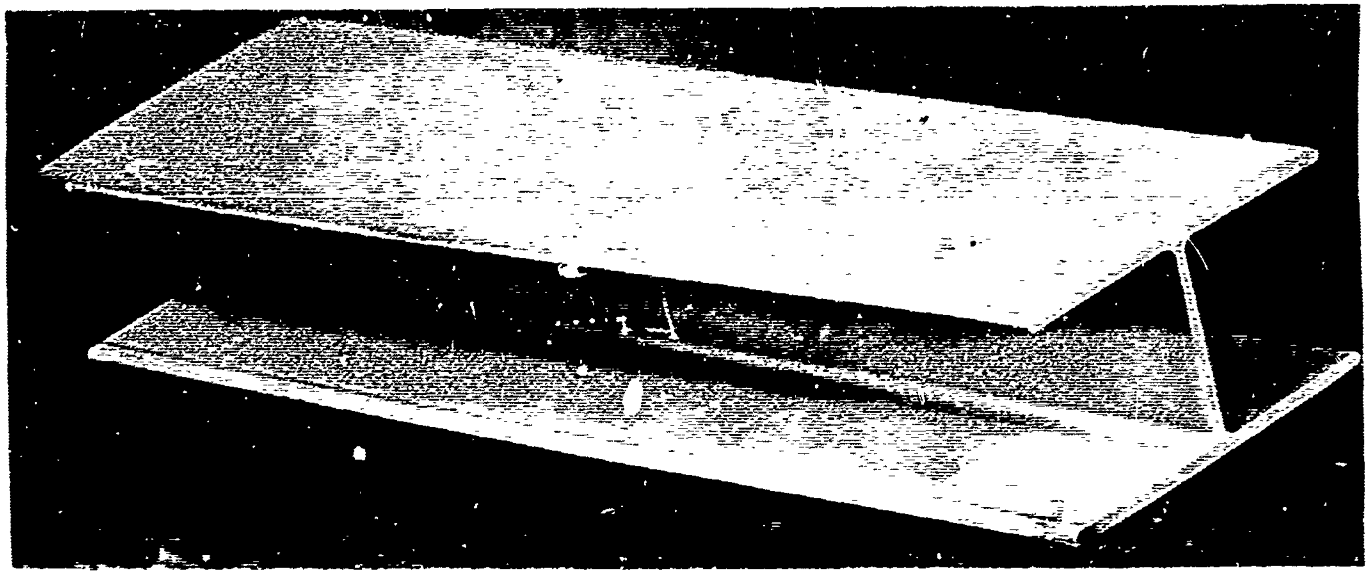
Back-End View
Magnification: 1X



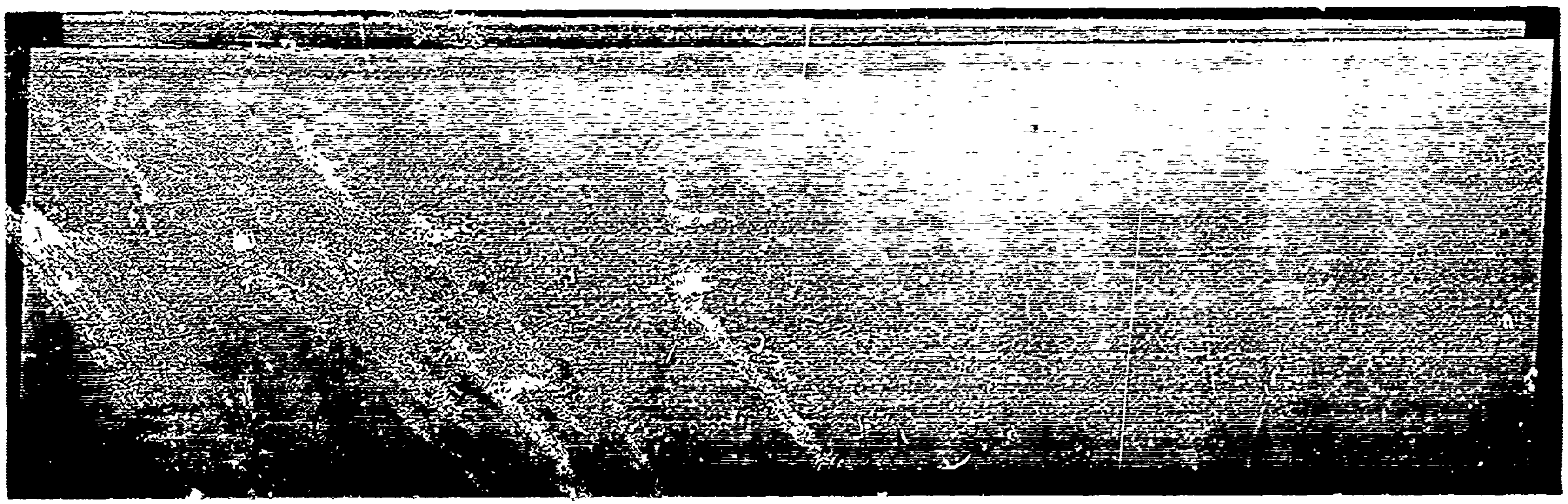
Back-Side View
Magnification: 1-1/4X

FIGURE 14

As-Extruded Surface After Sandblasting of TZM Extrusion No. 33



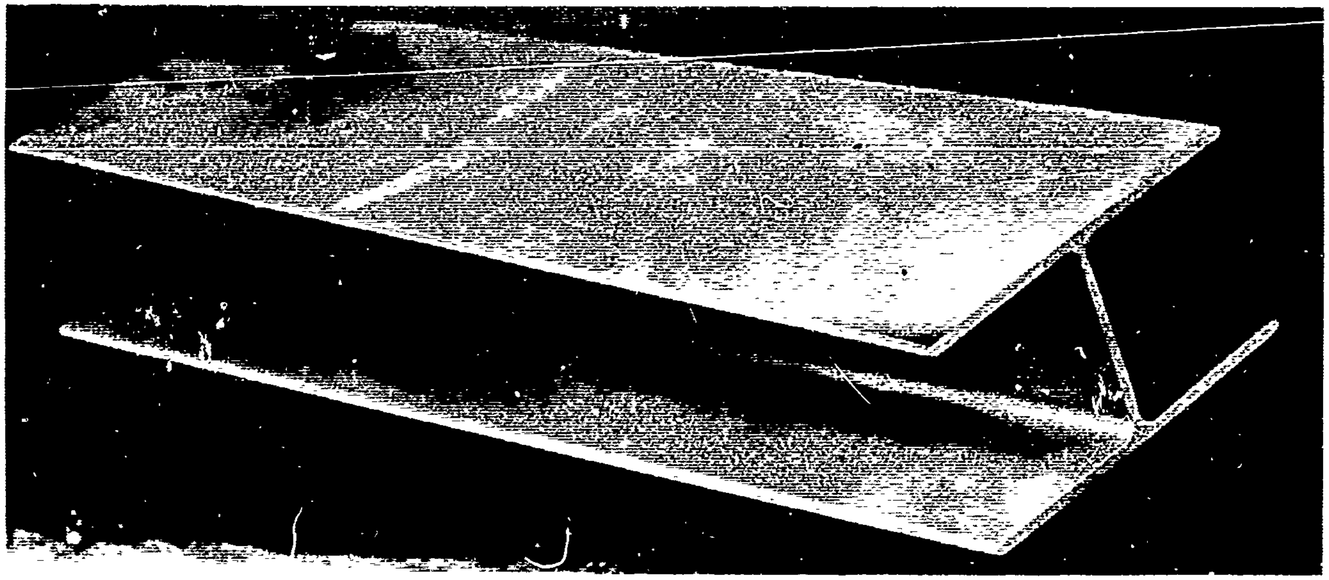
Back-End View
Magnification: 1X



Back-Side View
Magnification: 1-1/4X

FIGURE 15

As-Extruded Surface After Sandblasting of TZM Extrusion No. 34

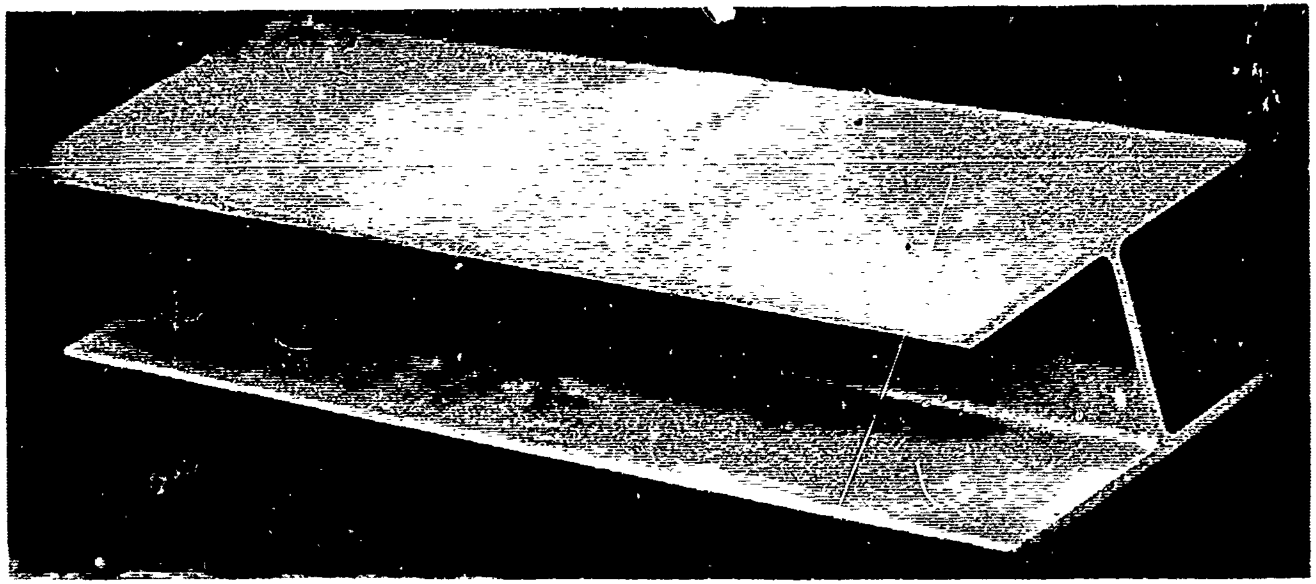


Back-End View
Magnification: 1X

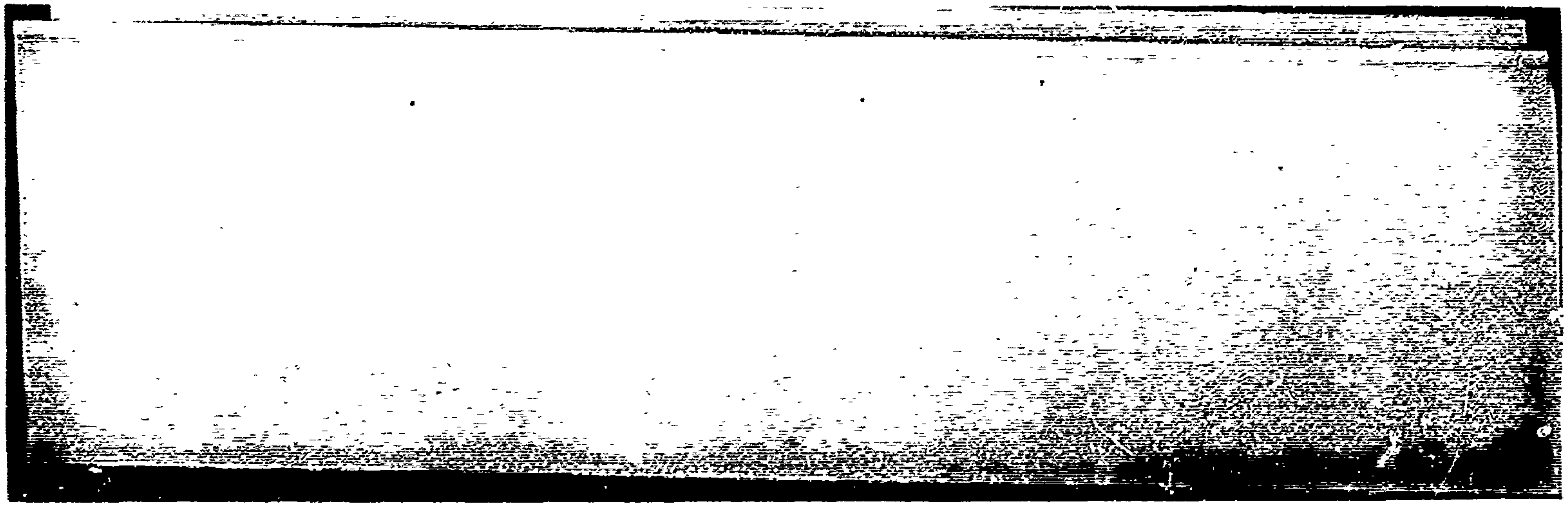
Back-Side View
Magnification: 1-1/4X

FIGURE 16

As-Extruded Surface After Sandblasting of TZM Extrusion No. 35



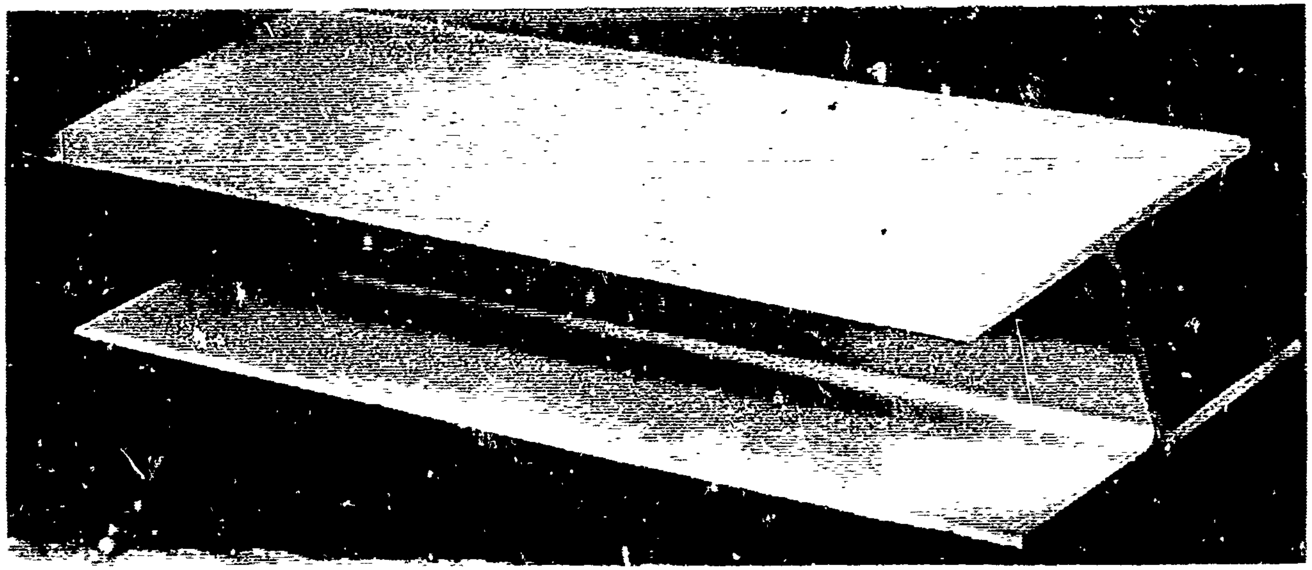
Back-End View
Magnification: 1X



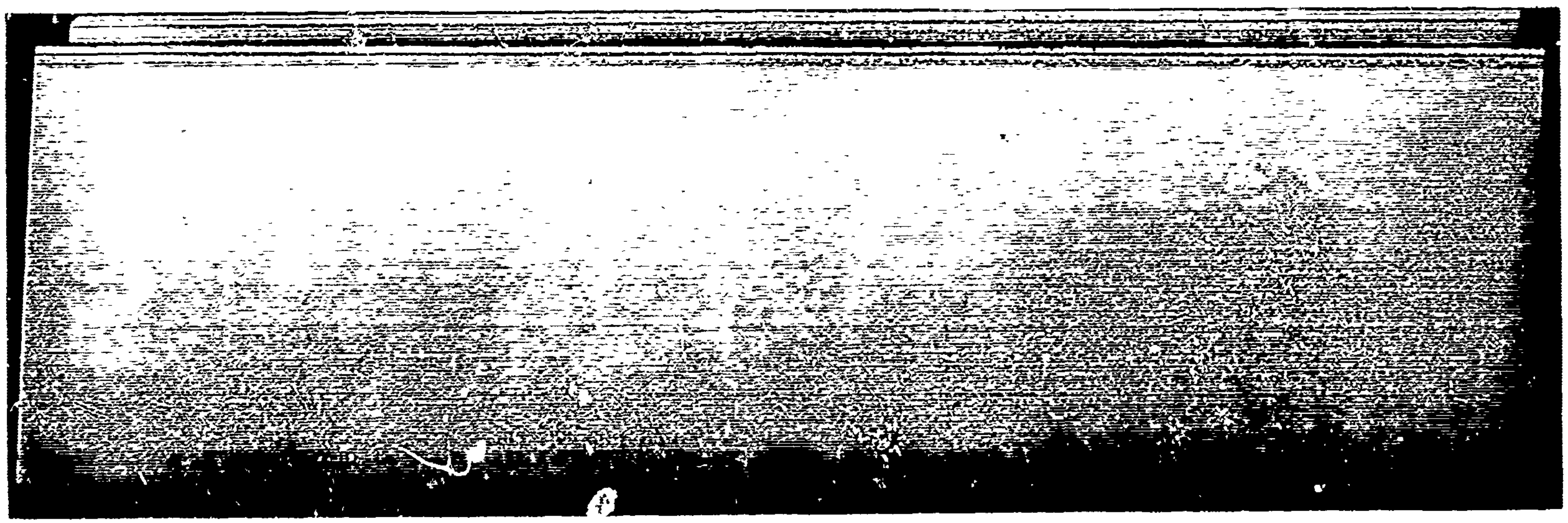
Back-Side View
Magnification: 1-1/4X

FIGURE 17

As-Extruded Surface After Sandblasting of TZM Extrusion No. 36



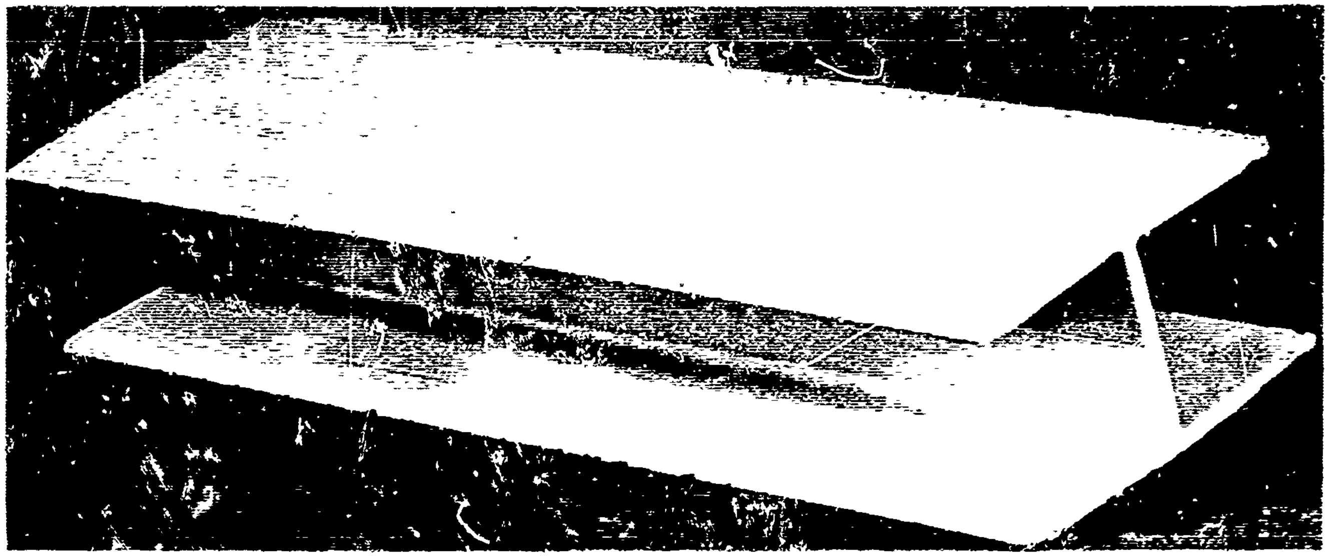
Back-End View
Magnification: 1X



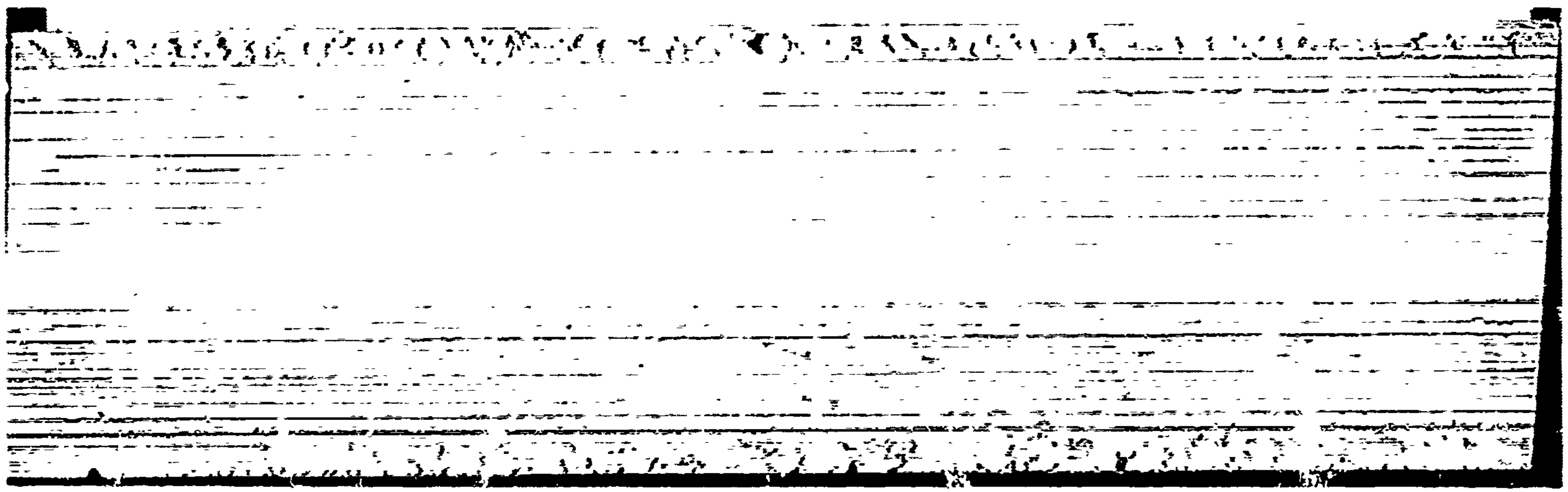
Back-Side View
Magnification: 1-1/4X

FIGURE 18

As-Extruded Surface After Sandblasting of TZM Extrusion No. 37



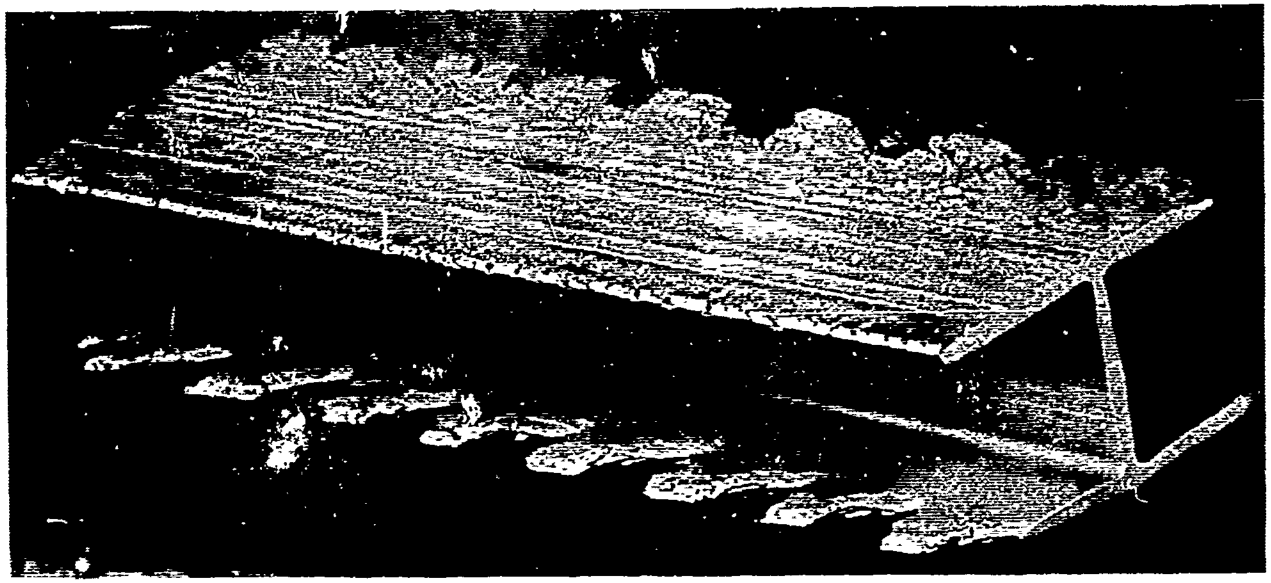
Back-End View
Magnification: 1X



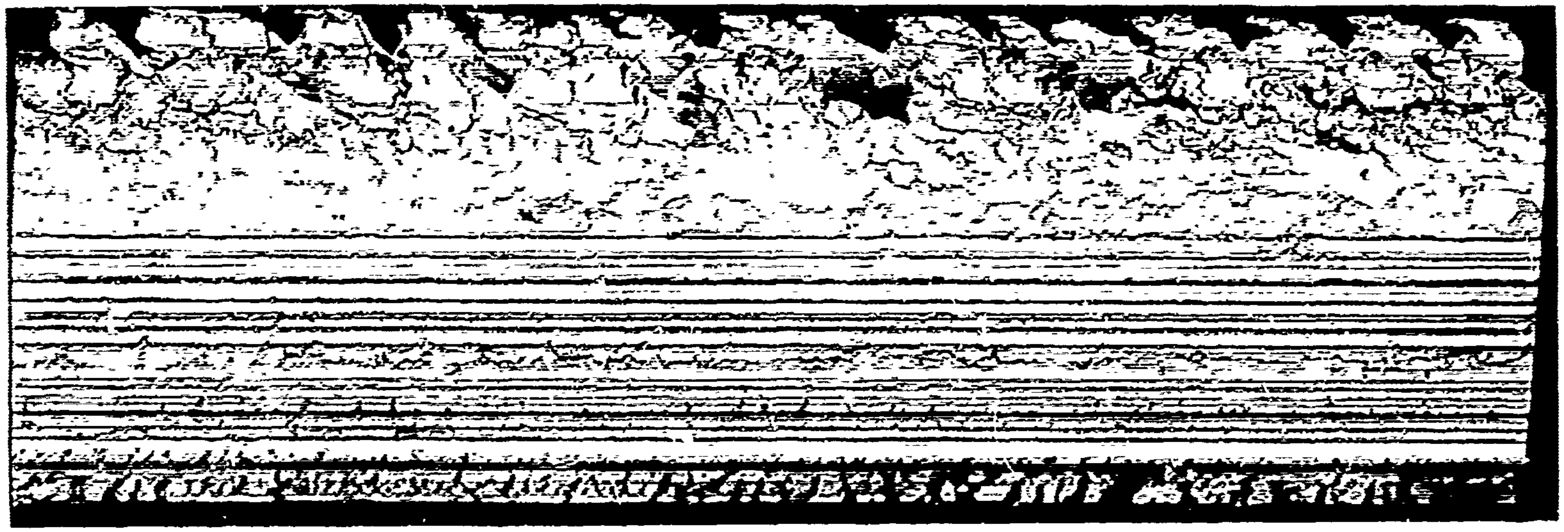
Back-Side View
Magnification: 1-1/4X

FIGURE 19

As-Extruded Surface After Sandblasting of TZM Extrusion No. 38



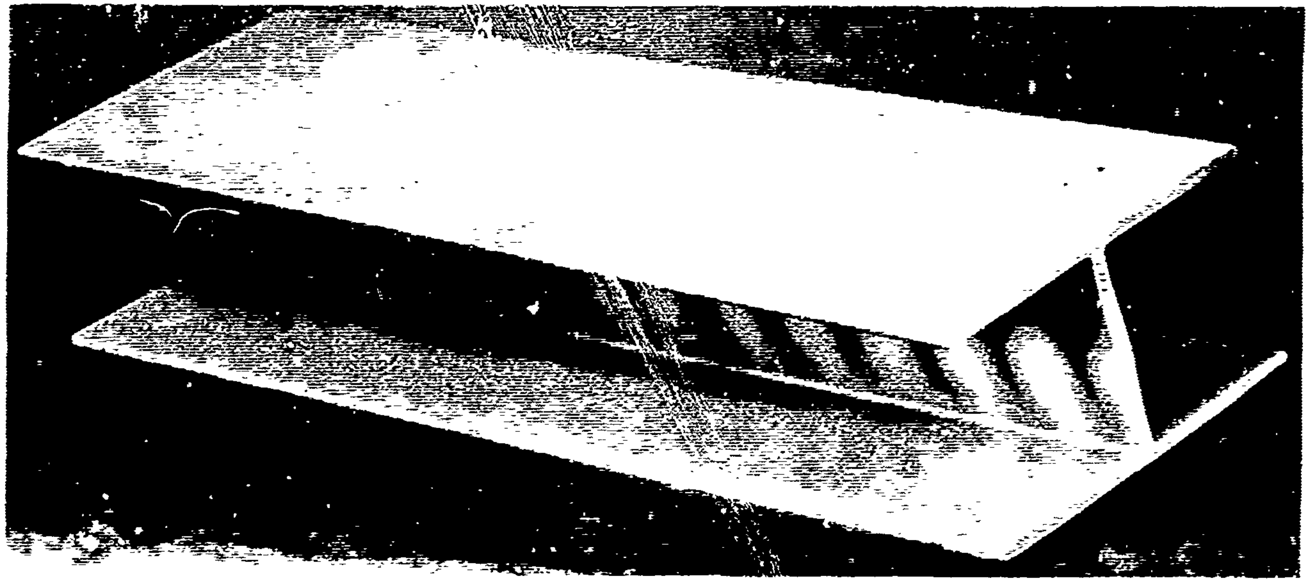
Back-End View
Magnification: 1X



Back-Side View
Magnification: 1-1/4X

FIGURE 20

As-Extruded Surface After Sandblasting of TZM Extrusion No. 39



Back-End View
Magnification: 1X

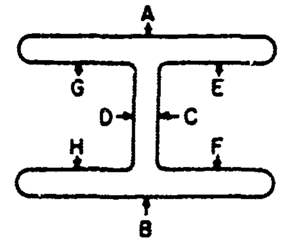
Back Side View
Magnification: 1- /4X

FIGURE 21

As-Extruded Surface After Sandblasting of TZM Extrusion No. 42

TABLE 19

Profilometer Surface Measurements of H-Shaped Extrusions
Average RMS of High Peaks



Extrusion Sequence Number		A		B		C		D		E		F		G		H	
		L	T	L	T	L	T	L	T	L	T	L	T	L	T	L	T
27:	Front	90-110	80-100	30-40	40-50	40-50	50-90	50-60	70-240	20-30	70-160	120-140	90-110	20-30	40-60	120-150	70-130
	Back	50-60	60-70	20-30	40-50	10	60-80	7	60-90	6-12	40-60	20-30	40-70	7-12	40-50	20-30	60-80
28:	Front	220-280	140-230	70-80	80-130	50-60	60-70	50-60	80-100	50-60	60-80	70-80	70-80	60-70	60-70	60-70	60-70
	Back	30-90	100-110	70-80	140-170	70-80	80-100	70-80	100-110	60-70	60-70	80-90	80-90	60-80	70-80	60-70	70-80
29:	Front	90-130	80-120	100-130	100-140	50-60	60-80	30-40	50-60	60-80	60-80	60-70	70-80	60-70	60-80	60-70	60-70
	Back	70-90	110-150	70-90	110-140	60-80	80-90	50-60	80-90	60-70	70-90	50-60	60-110	60-80	70-120	60-70	70-100
30:	Front	90-100	110-140	80-120	90-140	30-40	70-90	40-50	80-100	50-60	60-70	50-60	60-70	60-70	60-70	50-60	50-60
	Back	60-70	90-110	60-70	80-100	60-70	90-120	40-50	80-120	60-70	60-70	70-80	70-80	60-80	60-70	70-80	70-80
31:	Front	120-250	120-220	120-250	120-180	60-70	80-90	40-50	70-80	60-80	50-70	60-70	60-70	60-70	60-80	70-80	70-80
	Back	50-200	110-200	60-70	90-130	60-70	180-260	50	140-210	60-70	90-120	60-70	110-180	70-80	80-120	60-70	110-130
32:	Front	120-220	150-250	240-290	180-320	40-50	70-90	60-70	70-90	50-60	50-70	60-70	60-70	60-70	60-70	60-70	60-70
	Back	60-70	110-140	70-80	100-140	60-80	300-450	90-140	150-270	50-60	70-110	50-60	70-110	50-60	70-90	50-60	60-70
33:	Front	60-90	80-100	60-70	60-70	60-70	90-110	40-50	60-70	50-60	50-60	60-70	60-70	50-60	50-60	60-70	60-70
	Back	60-70	70-90	60-70	70-80	50-60	80-90	60-70	80-90	50-60	50-60	50-60	50-70	50-60	50-70	50	50-60
34:	Front	70-100	100-120	70-80	80-100	60-70	80-90	60-70	70-80	70-80	70-80	70-80	70-80	70-80	70-80	80-90	80-90
	Back	70-80	90-120	60-70	90-100	50-60	70-80	40-50	70-80	70-80	70-90	70-80	80-90	60-70	70-80	70-80	70-80
35:	Front	70-80	80-90	60-70	60-80	60-70	80-90	40	60-70	50-60	60-70	70-80	60-70	50-60	50-60	60-70	70-80
	Back	90-110	80-100	80-100	80-100	40-60	70-90	50-60	70-80	70-80	70-80	80-90	70-80	70-90	70-90	80-90	70-80
36:	Front	70-80	70-80	80-90	90-110	70-80	90-100	50-60	60-70	70-80	60-80	70-80	70-80	70-80	80-90	60-70	60-70
	Back	70-80	80-90	70-80	70-80	60-70	70-80	60-70	70-90	60-70	60-70	60-70	60-70	70-80	50-70	60-70	50-60
37:	Front	160-240	140-200	90-120	130-180	60-140	70-80	70-120	70-90	80-140	80-150	70-130	90-150	80-140	70-130	80-140	80-120
	Back	70-90	120-150	70-80	120-140	60-130	70-90	60-110	110-150	70-110	70-120	70-110	80-130	70-110	80-130	70-120	80-160
38:	Front	60-70	60-70	60-70	70-80	50-70	80-100	50-60	80-110	50-60	60-70	60-70	60-70	60-70	80-90	60-80	80-90
	Back	150-350	250-450	70-80	200-350	60-80	150-450	50-65	200-300	70-80	150-250	60-70	120-240	60-70	110-130	60-70	90-160
39:	Front	90-110	120-150	100-170	120-180	50-60	60-70	50-60	60-70	70-90	70-80	80-90	70-80	70-80	70-80	60-70	70-80
	Back	(1)	(1)	(1)	(1)	60-70	130-180	130-160	150-280	60-70	150-200	70-80	190-300	50-60	180-320	(1)	(1)
40:	Front	110-120	110-130	90-100	90-130	70-80	80-100	40-50	70-80	60-70	60-70	70-80	80-90	70-80	70-80	70-80	80-110
	Back	80-90	80-100	60-80	70-90	50-60	80-120	50-60	70-80	70-80	60-70	60-70	70-80	60-70	50-70	70-80	70-80
41:	Front	80-100	100-120	90-120	90-130	60-90	90-120	70-100	110-130	40-70	70-110	20-50	60-90	80-110	110-120	15-25	80-100
	Back	10	10-20	10	10-20	10-25	40-60	5-20	30-40	10	50-60	10	30-50	10	60-70	10-30	40-70
42:	Front	80-220	90-160	130-150	120-150	50-60	70-80	60-70	70-80	70-80	70-90	70-80	80-90	60-80	60-80	70-80	60-80
	Back	70-80	70-80	70-80	70-80	60-70	90-110	50-60	80-90	60-70	70-80	60-70	70-90	60-70	60-90	60-70	70-80

Extrusion Sequence Number	Visual Corner Appearance
27	Very slight fin all corners, poor corner fill
28	Slight fin all corners, poor corner fill
29	Poor corner fill
30	Very slight fin all corners, fair corner fill
31	Very slight fin all corners, good corner fill
32	Poor corners
33	Slight fin all corners, good corner fill
34	Very slight fin all corners, fair corner fill
35	Very slight fin all corners, fair corner fill
36	Slight fin all corners, fair corner fill
37	Slight fin all corners, fair corners
38	Very poor corners
39	Very poor corners
40	(no extrusion)
41	No fins, good corner fill
42	No fins, fair corner fill

Corner fins which normally appear from the use of die segments were slight regardless of extrusion conditions and die design. However, only short extrusions were made and this matter may become a problem when longer, 22-foot extruions will be made.

Corner fill or geometry was not good in most extrusions. It is believed that an improvement can be made in this regard by (1) a more refined billet structure to increase extrudability of TZM and (2) a revised conical entry design which will allow more metal to flow into the corners of the die orifice.

2. Metallurgical Evaluation

Transverse microstructures at the back location in the corner, fillet radius and stem center of some H-shaped extrusions were given in the previous interim technical engineering report.[3] These extrusions were made from 3100F 3200F billet temperatures. It is expected that extrusions made during this report period from this same temperature would be similar in microstructure. Specimen material from extrusions produced at a different temperature or reduction ratio is being prepared for examination.

As shown in the previous report, microstructures of H-shaped extrusions were fine grain regardless of location. A tendency for grain growth was noted at the fillet radius.

3. Mechanical Properties

Specimen material was taken from TZM H-shaped Extrusions No.s 22 and 23 accomplished during the previous report period.[3]

Tensile test results are given in Table 20. Specimen material before machining was given a stress relief heat treatment of 1 hour at 2000F in argon.

Good ductility was found regardless of specimen location and direction. Strength values appeared close to values normally found in recrystallized TZM bar material also given in Table 20. Typical values for recrystallized sheet material were not available. It should be noted as a trend that properties can be improved by lower billet temperature. Good test results, as given in Table 20 for round Extrusion No. 17 made from 3000F billet temperature, suggest this temperature as a goal for this program.

Transverse and longitudinal bend tests were made with a deflection speed of 5 inches per minute in a 135-degree die seat. The results of the tests are given in Tables 21 and 22 and in Figures 22 through 26.

Excellent bend ductility was found at room temperature for both extrusions regardless of test direction. Transition bend temperature (1T bend radius) was the following:

Extrusion No. 22

Longitudinal	-100F to -75F
Transverse	(not well established)

Extrusion No. 23

Longitudinal	+35F to +50F
Transverse	0F to +25F

Again, it should be noted as a trend that the bend transition temperature was improved by lower billet temperature.

Full "H" cross-section specimens were taken from Extrusion No. 37 in the as-extruded condition for tensile and compression tests at room temperature. The results are given in Table 23. Figures 27 through 29 show compression test sections after testing. Reasonable load carrying ability by these extrusion sections was noted in these tests. However, yield and ultimate strength values were almost identical regardless of testing procedure, suggesting low tolerance for plastic deformation at room temperature.

4. Rollability

Flange material was obtained from Extrusion No. 23 for rolling on a 4-high Stanat mill with 10, 20 and 30 percent reductions per pass from 1200F furnace preheat temperature. Temperature during rolling was within the range of 700F to 900F. Average Vickers hardness versus rolled size and percent reduction is shown in Figure 30. Transverse microstructures are shown in Figures 31 through 33.

TABLE 20

Room Temperature Tensile Tests
As-Extruded H-Shaped Material
(Stress Relieved Condition)

Strain Rate to Yield 0.005 in/in/min
Strain Rate to Fracture 0.05 in/in/min

Extrusion Number	Extrusion Billet Temperature (°F)	Location	Specimen Thickness	Ultimate (ksi)	0.2% Y.S. (ksi)	.02% Y.S. (ksi)	% Elong.	E x 10^{-6}
22	3100	Stem	.051	72.7	65.4	57.6	22.5	47.5
		Stem	.051	73.9	66.1	49.0	18.6	52.1
		Flange	.061	75.6	67.6	58.8	26.0	49.3
		Flange	.061	74.1	62.0	48.6	41.5	40.5
23	3200	Stem	.035	73.7	57.0	42.5	14.9	53.6
		Stem	.035	73.7	56.1	49.3	11.4	51.0
		Flange	.058	74.0	63.1	50.9	14.5	44.1
		Flange	.060	71.6	59.9	51.5	30.4	38.8
17	3000	Round	.251	94.6	75.5	69.4	17.1	54.3
Bar(1)				80.0	55.0		20	

(1) Bar less than 2-inch diameter in recrystallized condition, Climax Specification Number CMX-WB-TZM-2, May 1964.

NOTE: All Specimens Stress Relieved 2000F - 1 hour in Argon

TABLE 21

Bend Tests - Extrusion Number 22
As-Extruded and Stress Relieved Material
Extrusion Billet Temperature 3100F
Reduction Ratio 41.5:1
Punch Travel 5 Inches per Minute

Bend Radius	Specimen Temperature (°F)	Bend Angle (°)
Longitudinal		
1T	+73°	130 (Flattened to 170°)
1/2T	+73°	130
1/3T	+73°	130
1T	+50°	130
1T	0°	130
1T	-50°	130
1T	-75°	130
1T	-100°	115
Transverse		
1T	+74°	130
1T	+74°	30
1T	0°	10

NOTE: All Specimens Stress Relieved 2000F - 1 hour in Argon

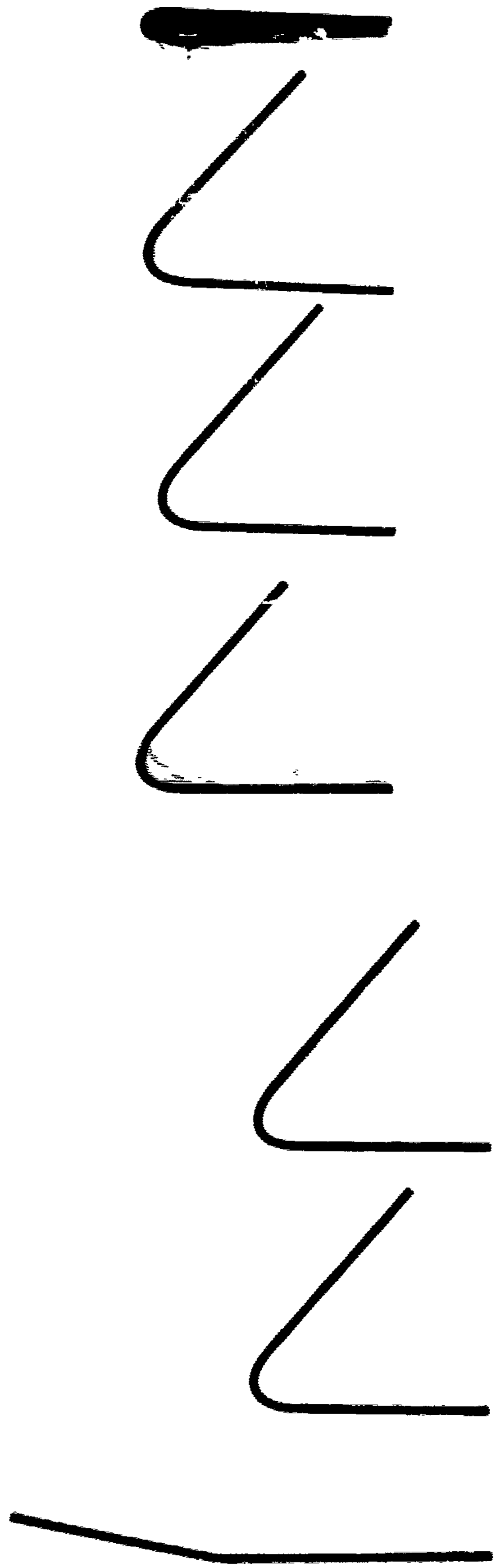
TABLE 22

Bend Tests - Extrusion Number 23
As-Extruded and Stress Relieved Material
Extrusion Billet Temperature 3200F
Reduction Ratio 40.9:1
Punch Travel 5 Inches per Minute

Bend Radius	Specimen Temperature (°F)	Bend Angle (°)
Longitudinal		
1T	+73°	130 (Flattened to 170°)
1/2T	+73°	130
1/3T	+73°	10
1T	+50°	130
1T	+35°	120
1T	+25°	10
1T	0°	5
Transverse		
1T	+74°	130 (Flattened to 180°)
1T	+25°	130
1T	0°	130 (Cracked)
1T	-25°	120 (Broken)

NOTE: All Specimens Stress Relieved 2000F - 1 hour in Argon

Test Temperature (F)	Angle of Fracture (°)
+73	130 (Flattened to 170)
(1) +73	130
(2) +73	130
+50	130
0	130
-75	130
-100	10



(1) 1/2T Bend Radius
(2) 1/3T Bend Radius

FIGURE 22

Longitudinal Bend Tests - Extrusion No. 22
Magnification: 3/4X

Test Temperature (F)	Angle of Fracture (°)
+74	130 (Cracked)
+74	30 (Broken)
+74	130 (Flattened to 170)
-50	35 (Broken)
-50	15 (Broken)
0	10 (Broken)

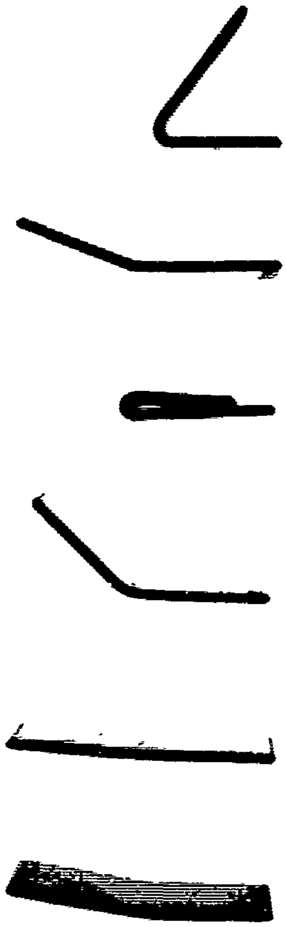
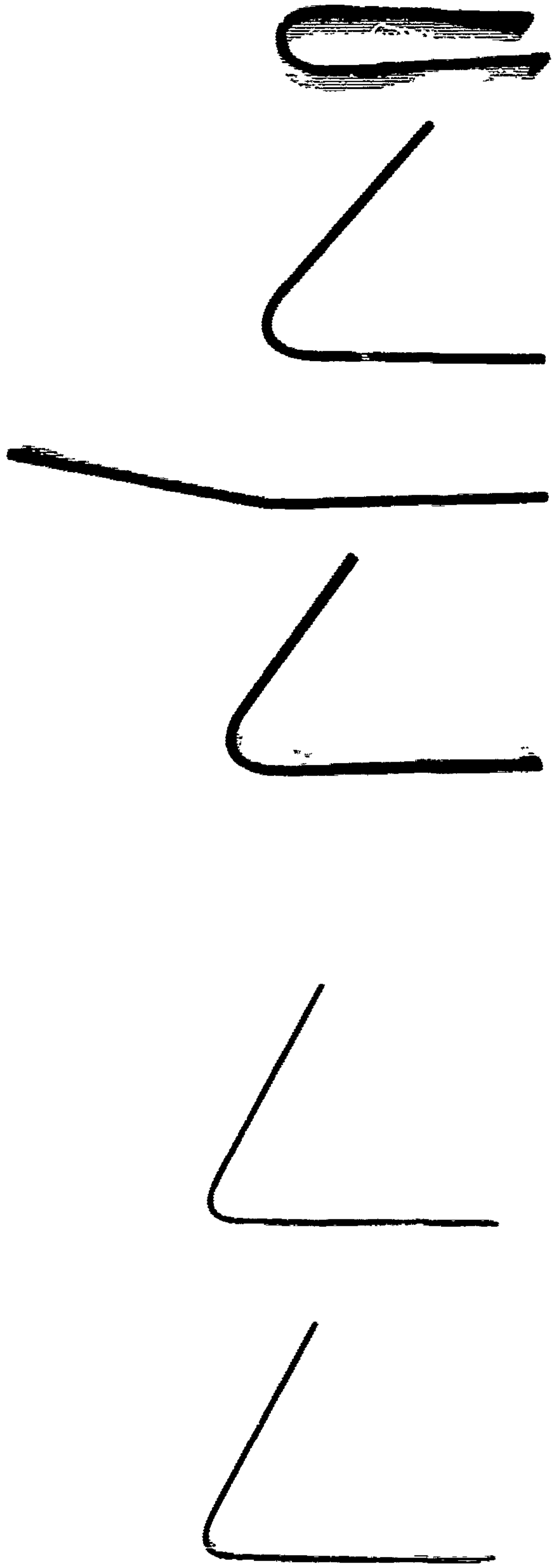


FIGURE 23

Transverse Bend Tests - Extrusion No. 22
Magnification: 3/4X

Test Temperature (F)	Angle of Fracture (°)
+73	130 (Flattened to 170)
(1) +73	130
(2) +73	10 (Broken)
+50	130
+50	120 (No Cracking- High Spring Back)
+35	120 (No Cracking- High Spring Back)



(1) 1/2T Bend Radius
(2) 1/3T Bend Radius

FIGURE 24

Longitudinal Bend Tests - Extrusion No. 23
Magnification: 3/4X

Test Temperature (F)	Angle of Fracture (°)
0	5 (Broken)
0	5 (Broken)
0	35 (Broken)
+25	10 (Broken)

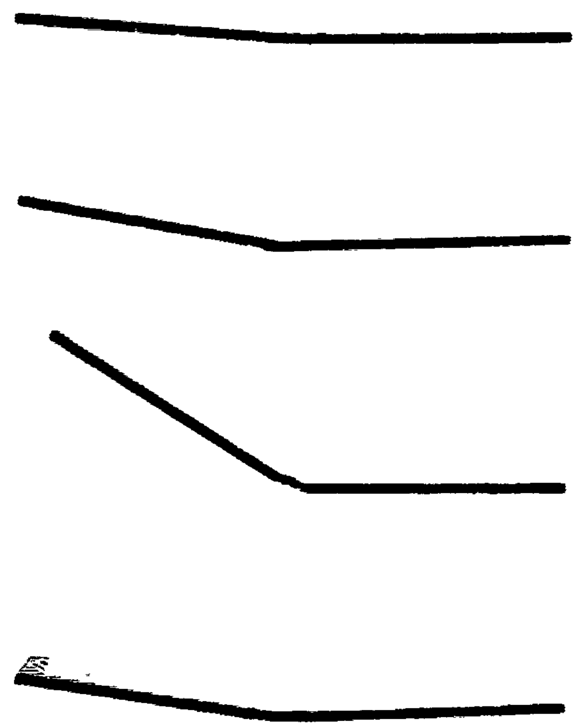
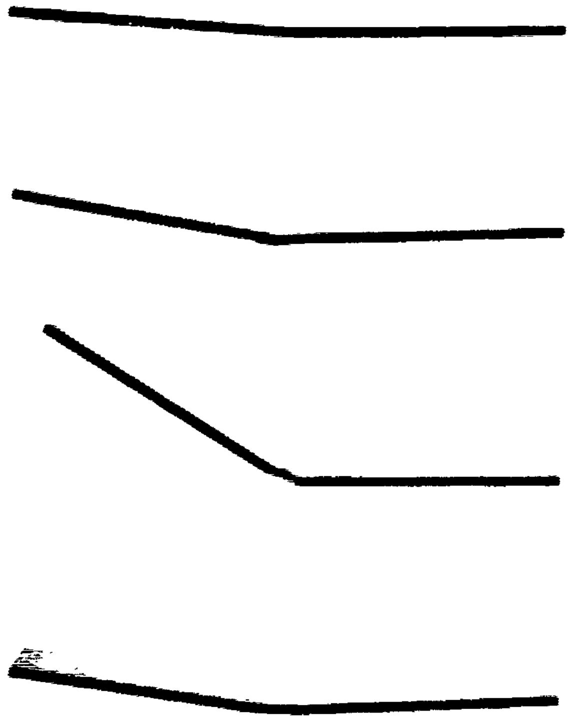


FIGURE 25

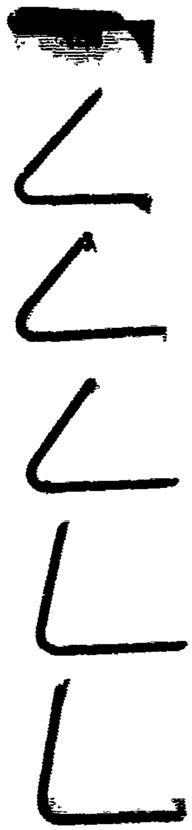
Longitudinal Bend Tests - Extrusion No. 23
Magnification: 3/4X



Test Temperature (F)	Angle of Fracture (°)
0	5 (Broken)
0	5 (Broken)
0	35 (Broken)
+25	10 (Broken)

FIGURE 25

Longitudinal Bend Tests - Extrusion No. 23
Magnification: 3/4X



Temperature (F)	Angle of Fracture (°)
+74	130 (Flattened to 170)
+74	130
+25	130
0	130 (Broken)
-25	120 (Cracked)
-50	120 (Broken)

FIGURE 26

Transverse Bend Tests - Extrusion No. 23
Magnification: 3/4X

TABLE 23

Room Temperature Tensile and Compression Tests - Extrusion Number 37
Full "H" Cross-Section
As-Extruded Condition
Extrusion Billet Temperature 3200F
Reduction Ratio 44.1:1

Specimen Length (inches)	Type of Test	Cross-Sectional Area (in^2)	Load at Failure (pounds)	Stress at Failure (ksi)	.2% Y.S. (ksi)	E x 10^{-6}
12	Tension	.262	12,200	45.6	39.6	37.6
12	Tension	.264	10,540	39.9	38.3	35.9
12	Compression	.260	11,500	44.2	--	45.0
2	Compression	.268	13,000	48.5	47.0	45.0

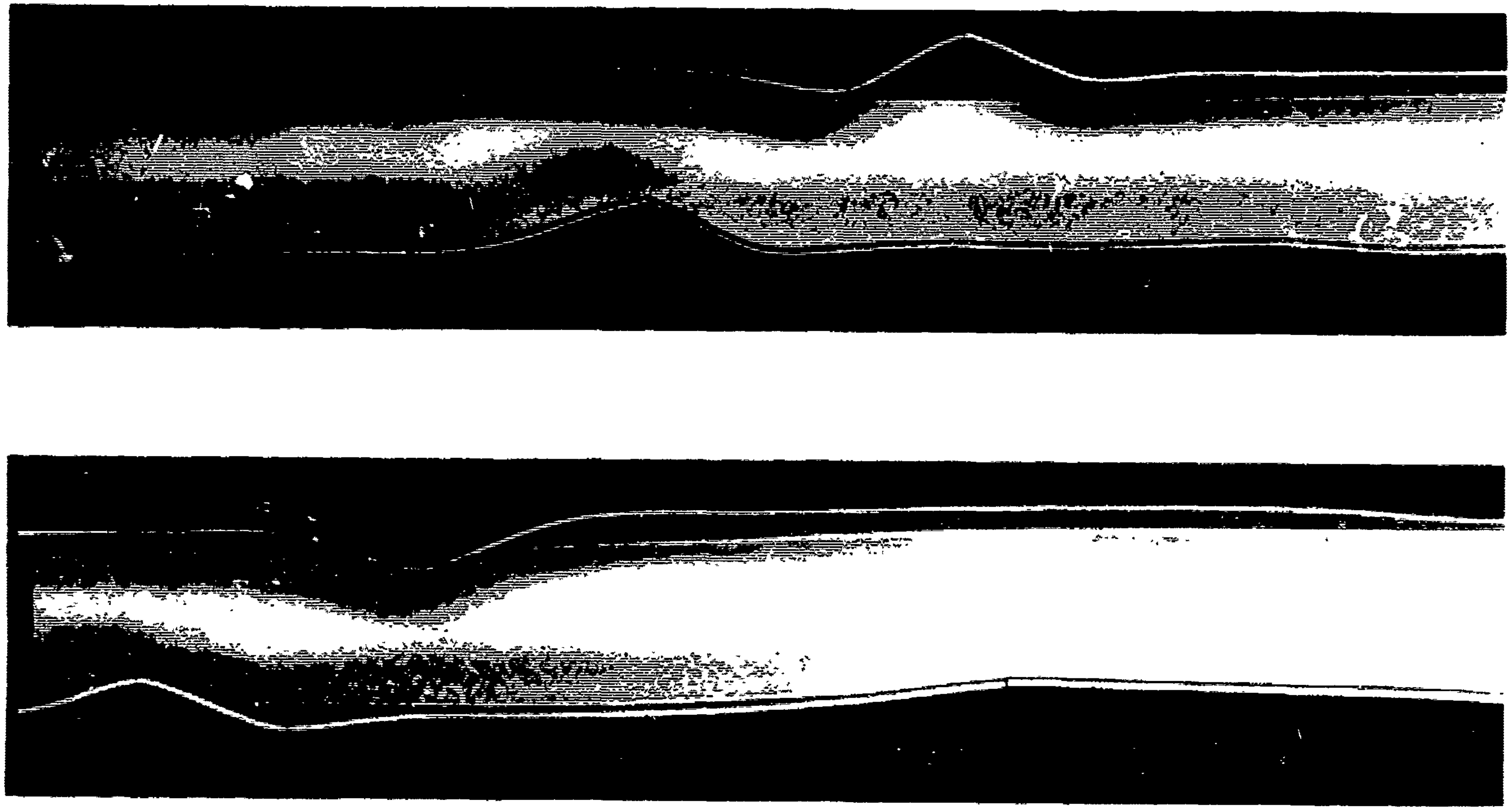


FIGURE 27

Edge Views of 12-Inch Long Full H-Shaped Compression Test
Section From Extrusion No. 37 After Testing at Room Temperature
Magnification: 1X

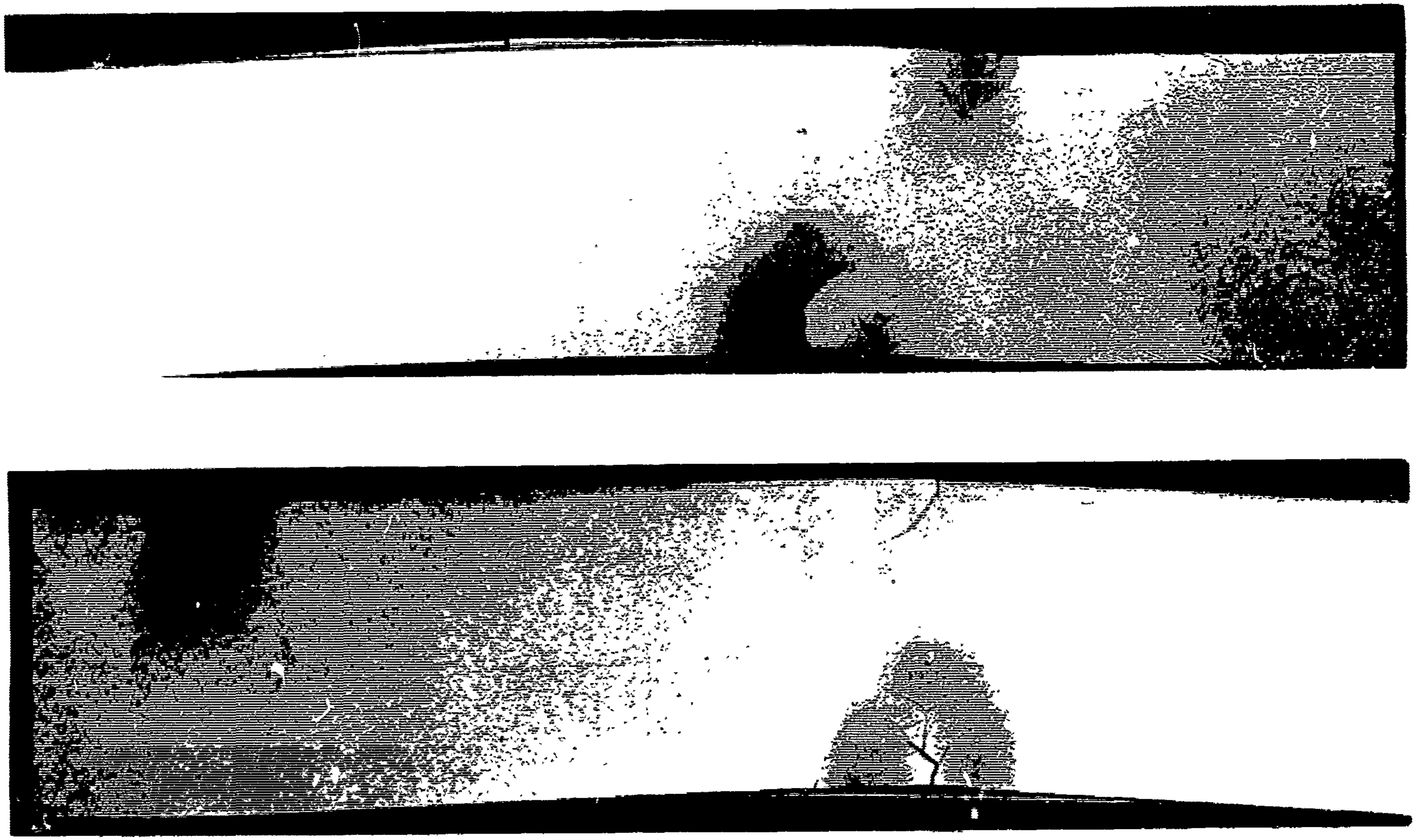
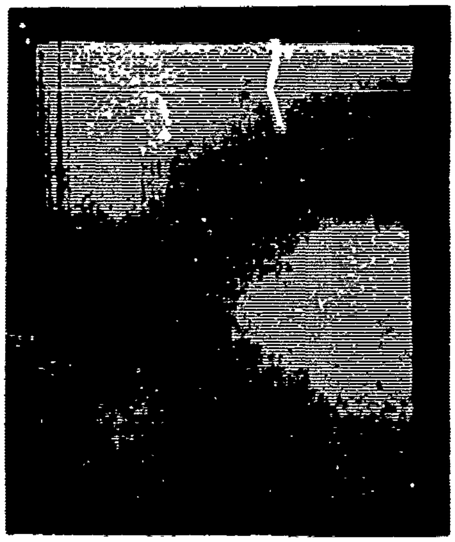
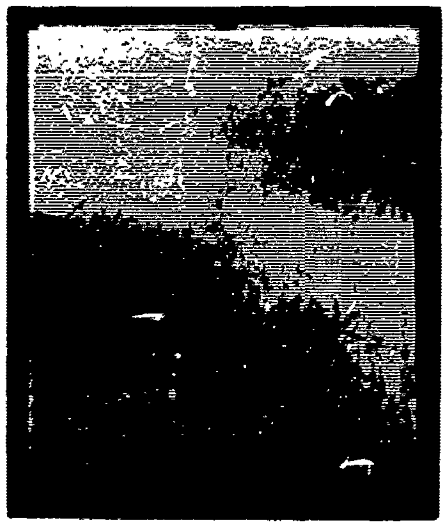


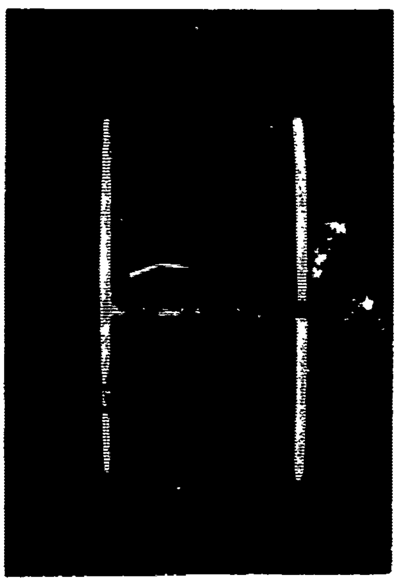
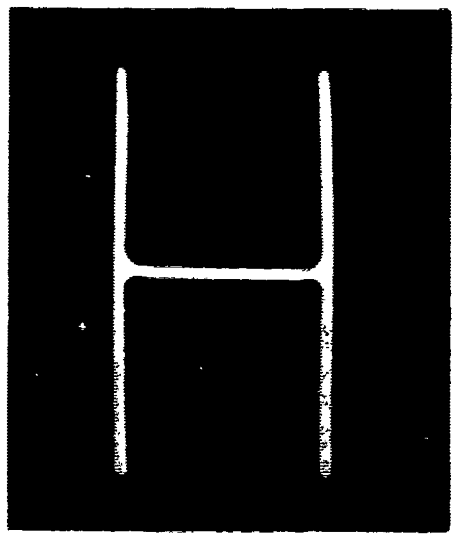
FIGURE 28

Side Views of 12-Inch Long Full H-Shaped Compression Test Section From Extrusion No. 37 After Testing at Room Temperature Magnification: 1X


Edge Views

Side Views

End Views

FIGURE 29

Two-Inch Long Full H-Shaped Compression Test
Specimen From Extrusion No. 37 After Testing at Room Temperature
Magnification: 1X

Average Vickers Hardness Versus Rolled Size, Percent Reduction
Furnace Preheat Temperature for Rolling 1200F
Flange Material from Extrusion No. 23

Extrusion Billet Temperature 3200F
Reduction Ratio 40.9:1
Stress Relieve 2000F - 1 Hour in Argon Before Rolling

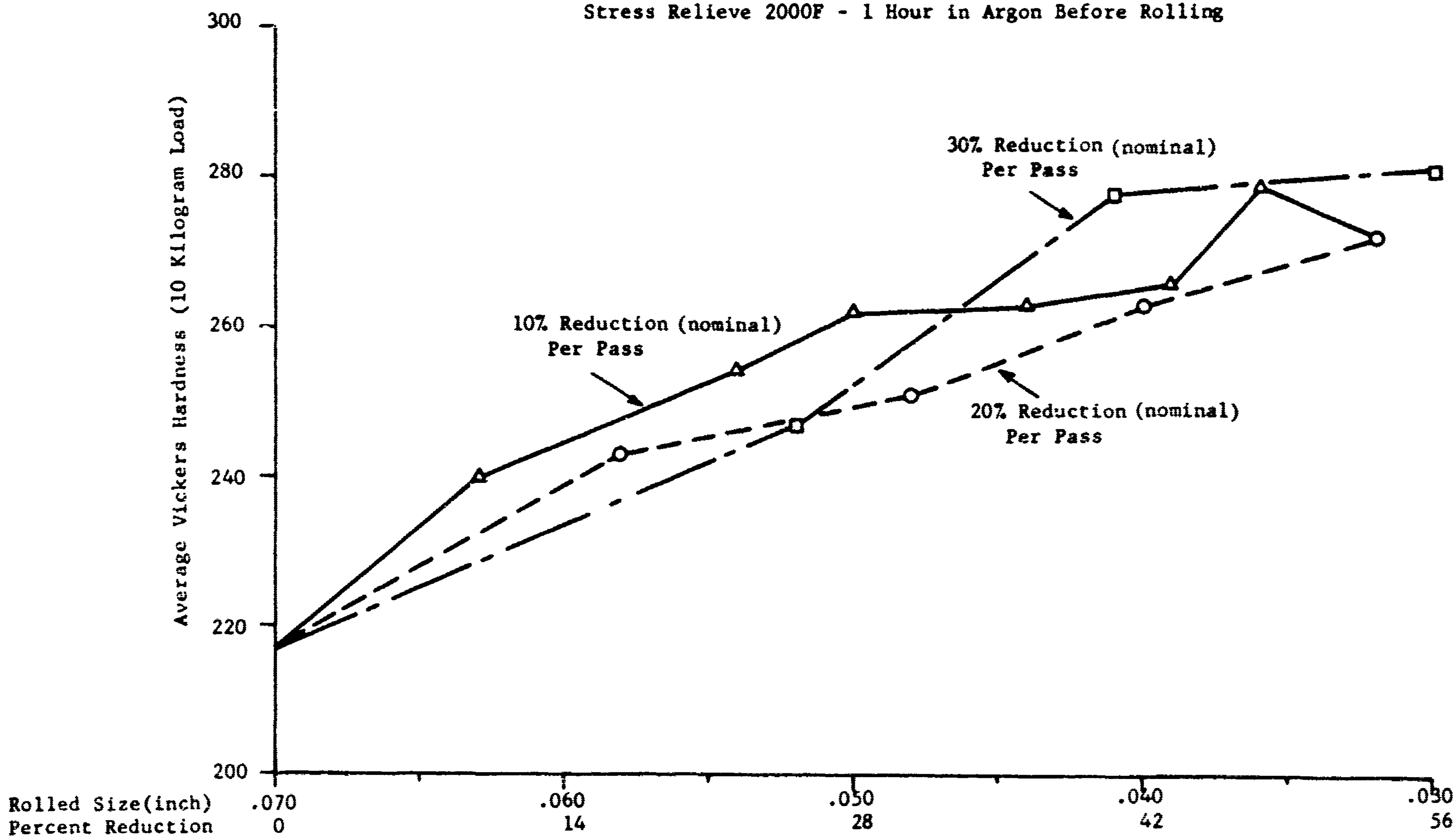
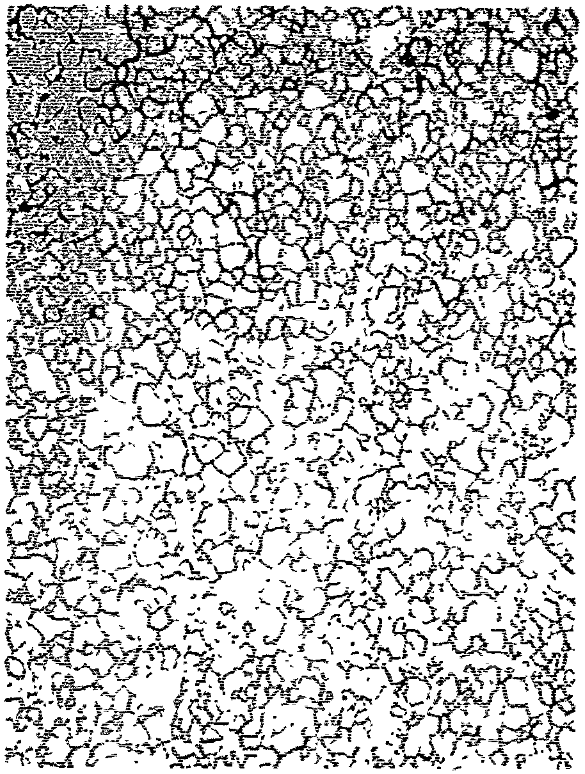


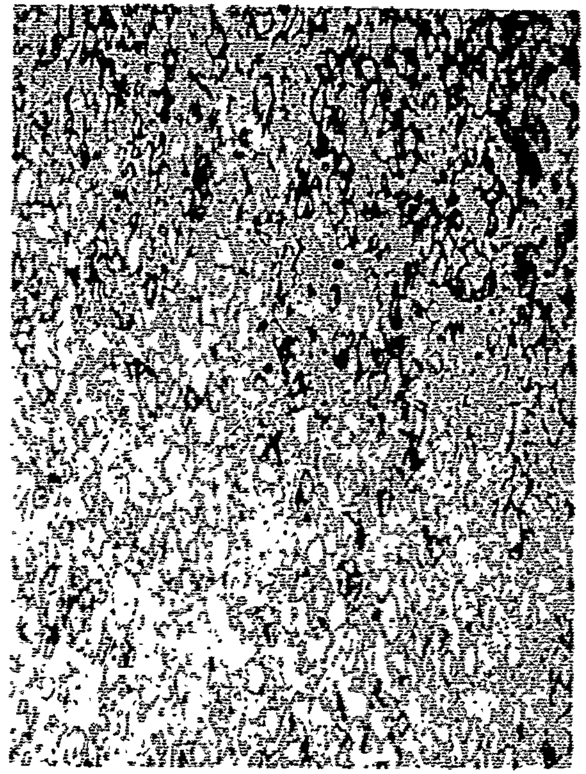
FIGURE 30

Hardness Versus Rolled Size or Percent Reduction for Flange Material From Extrusion No. 23



.063-Inch Thickness
10% Total Reduction
240 Vickers

.039-Inch Thickness
44% Total Reduction
266 Vickers

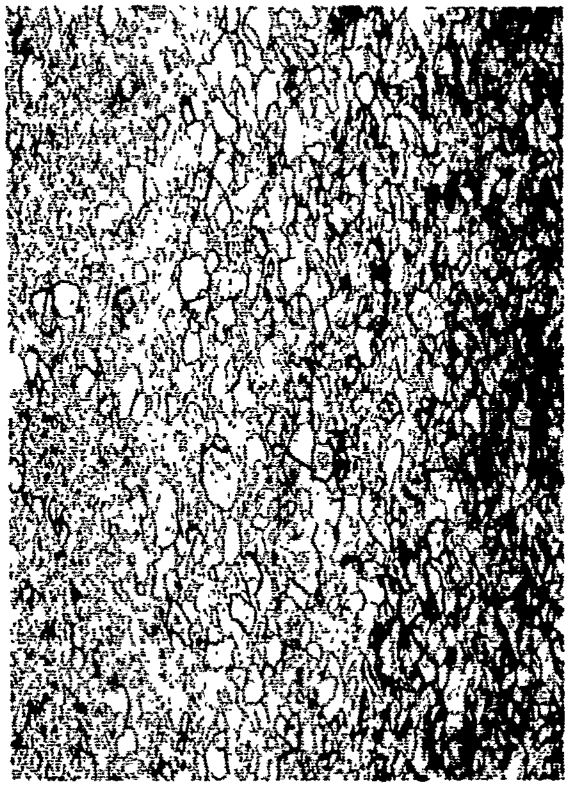


.032-Inch Thickness
54% Total Reduction
272 Vickers

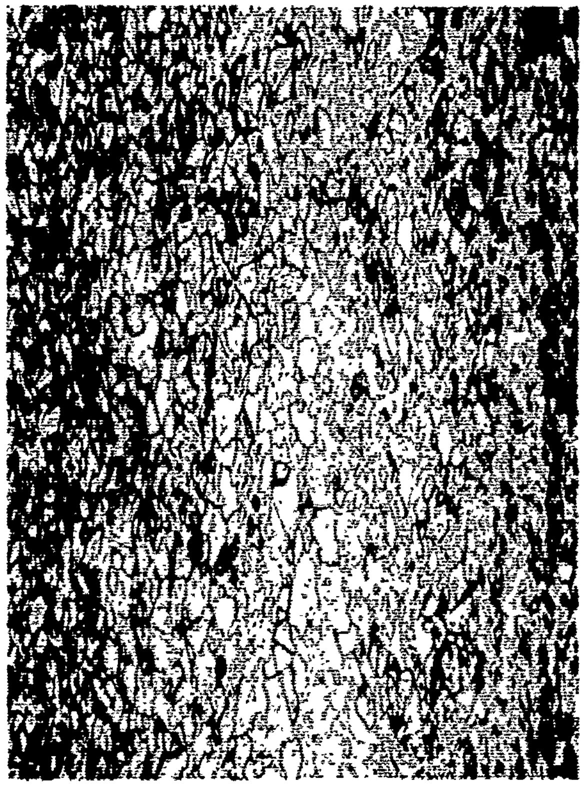
Etchant: 10% NaOH - Electrolytic
Magnification: 100X

FIGURE 31

Transverse Microstructures of Flange Material From Extrusion No. 37 After Rolling With Nominal 10-Percent Reduction Per Pass From Furnace Preheat Temperature of 1200F



.040-Inch Thickness
43% Total Reduction
261 Vickers



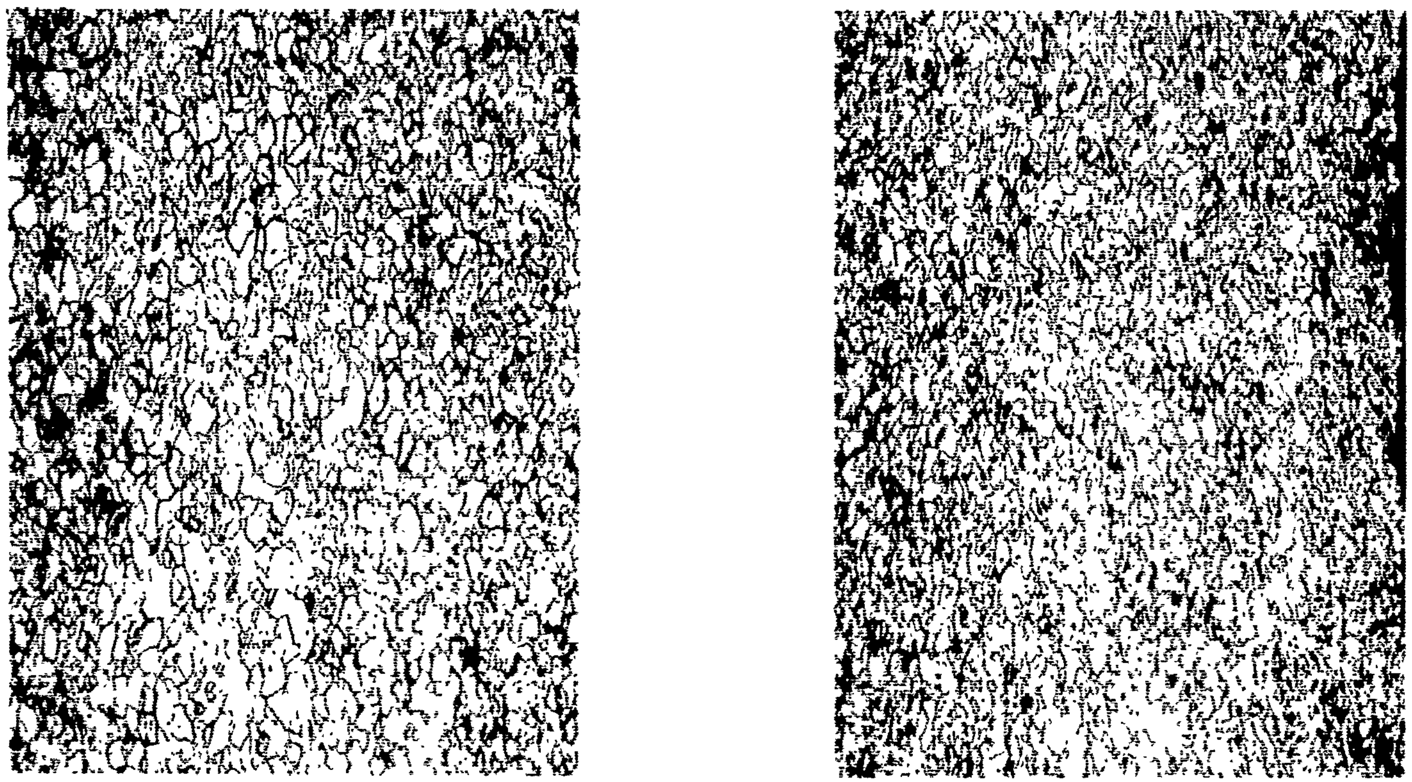
.032-Inch Thickness
54% Total Reduction
274 Vickers

Etchant: 10% NaOH - Electrolytic
Magnification: 100X

FIGURE 32

Transverse Microstructures of Flange Material from Extrusion No. 37 After Rolling With Nominal 20-Percent Reduction Per Pass From Furnace Preheat Temperature of 1200F

1/2 FRAMES



.041-Inch Thickness
41% Total Reduction
280 Vickers

.030-Inch Thickness
57% Total Reduction
283 Vickers

Etchant: 10% NaOH - Electrolytic
Magnification: 100X

FIGURE 33

Transverse Microstructures of Flange Material From Extrusion No. 37 After Rolling With Nominal 30-Percent Reduction Per Pass From Furnace Preheat Temperature of 1200F

1/2
FRAMES

In general, substantial increase in hardness and a fairly well worked structure were found after about 40 percent total reduction, particularly with 30 percent nominal reduction per pass. These results suggest that the extrusion of TZM to 0.062-inch thickness with same degree of work hardening followed by warm drawing to 0.040-inch thickness may produce reasonably good engineering properties.

REFERENCES

1. Santoli, P. A., "Extruding and Drawing Molybdenum to Complex Thin H-Section," First Interim Technical Engineering Report, RTD Interim Report 8-112 (I), Air Force Contract AF 33(657)-11203, October 1963.

2. Santoli, P. A., "Extruding and Drawing Molybdenum to Complex Thin H-Section," Second Interim Technical Engineering Report, RTD Interim Report 8-112 (II), Air Force Contract AF 33(657)-11203, January 1964.

3. Santoli, P. A., "Extruding and Drawing Molybdenum to Complex Thin H-Section," Third Interim Technical Engineering Report, RTD Interim Report 8-112 (III), Air Force Contract AF 33(657)-11203, May 1964.

4. Moly-Spray-Kote is a dispersion of molybdenum disulfide in a carefully selected blend of solvents and Freon propellants and is supplied by the Alpha Molykote Corporation.

5. Molykote G contains MoS_2, oil and lithium grease and is supplied by the Alpha Molykote Corporation.

APPENDIX I

THE EXTRUSION OF POWDER METALLURGY TZM
TO H-SHAPED CROSS-SECTION

In cooperation with

R. B. Bargainnier
Sylvania Electric Products Inc.
Subsidiary of
General Telephone and Electronics Corporation
Towanda, Pennsylvania

APPENDIX I

THE EXTRUSION OF POWDER METALLURGY TZM TO H-SHAPED CROSS-SECTION

SUMMARY

Four billets of powder metallurgy TZM were purchased from Sylvania Electric Products Inc. Three of these billets were extruded by Allegheny Ludlum to "H" shape of nominal 0.062-inch web thickness from billet temperatures of 2800F, 3000F and 3200F.

Excellent surface quality and dimensional runout characterized each extrusion, regardless of billet temperature. Extruded material was recrystallized even from the low temperature of 2800F and more finely grained than the original sintered billet. Room temperature strength, ductility and hardness were low. Density of as-extruded material was equivalent to arc-cast TZM.

INTRODUCTION

Powder metallurgy TZM became of interest in this program for its low cost and resistance-to-deformation at billet temperatures. Furthermore, adequate billet sizes of this material were available with the same nominal chemistry as produced by arc-casting. However, it was expected that interstitial elements such as oxygen, hydrogen and nitrogen will be present at higher levels. The effect of higher interstitial levels on the properties of extruded material produced in this program under unusual conditions could not be predicted. Actual extrusions would therefore be necessary in order to make this determination.

Description and evaluation of powder metallurgy TZM were given in previous interim technical engineering reports.(1)(2) Macrostructural examination revealed a uniform structure without porosity, non-metallic inclusions, sonims or chemical segregation. Search traces on a microprobe indicated quite good chemical homogeneity comparable with wrought arc-cast TZM material. Evaluation of extruded material was performed mainly by Sylvania Electric Products Inc. under the direction of Mr. R. B. Bargainnier. The results of this evaluation are given in this Appendix.

DISCUSSION

Extrusion No. 36 was accomplished from 2800F billet temperature to nominal 0.062-inch web thickness, corresponding to a reduction ratio of 45.6:1. This extrusion was evaluated for density, microstructure, hardness, chemistry and tensile properties.

Density

Two sections were obtained from Extrusion No. 36 for density measurements. One section was 4 inches long having a full "H" cross-section and the other was only a 4-inch long flange section. The results are the following:

Section	Method	Density (gms/cc)
Full "H"	Mercury displacement	10.11
	Mercury displacement	10.09
Flange	Benzene displacement	10.17

The average determination, therefore, is 10.12 grams per cubic centimeter which is considered to be fully dense.

Microstructure

Transverse microstructures at the back location of Extrusion No. 36 are shown in Figures 34 and 35. A fine recrystallized grain structure was observed having the following ASTM grain size:

Location	ASTM Grain Size
Corner	10
Fillet radius	6-8
Stem center	10

The grain size of the original sintered billet was ASTM 6-7.

It was also observed that precipitation, and/or inclusions were present at the grain boundaries and within the grains regardless of location. A considerable quantity of second phase (50 microns in diameter) was also found in the original billet structure but the grain boundaries appeared quite free of this second phase.[2] Changes in microstructure after extrusion may be due to one or a combination of the following:

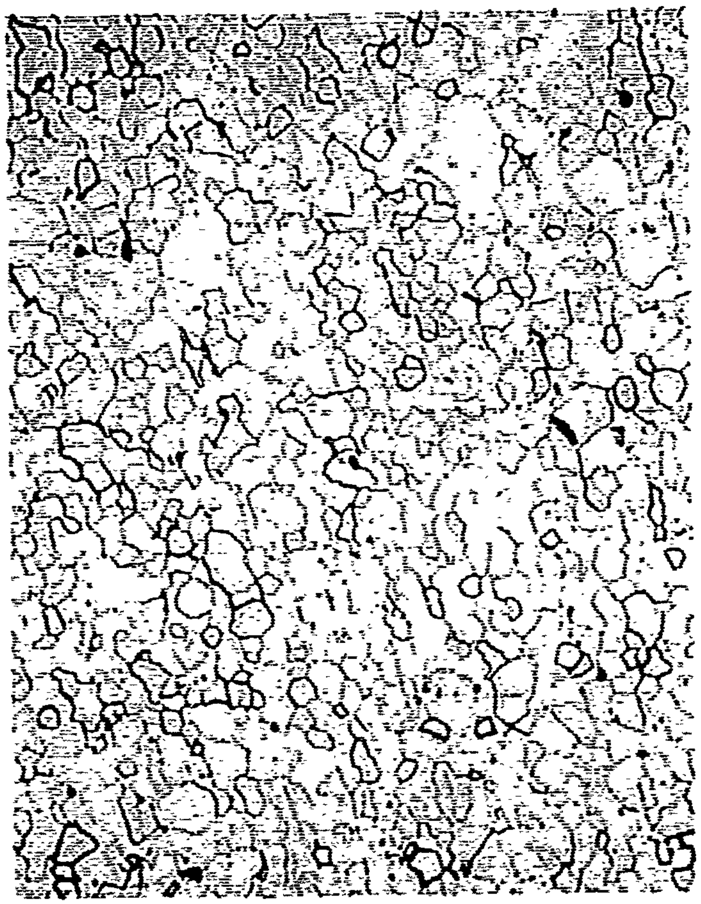
1) Changes in solubility of original interstitials which formed a second phase upon heating

2) Absorption of interstitials during heating which formed a second phase

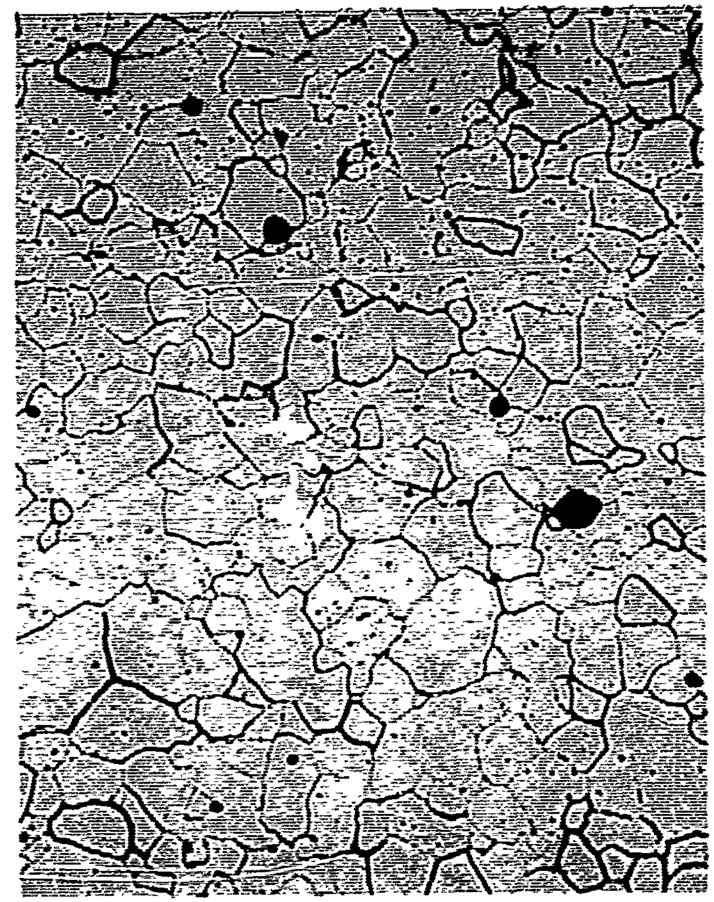
3) The influence of deformation and temperature during extrusion.

Hardness

Eleven determinations of hardness in DPH values under 10 kilogram load were made on the transverse cross-section at the back location of Extrusion No. 36. The following are the results:



Corner

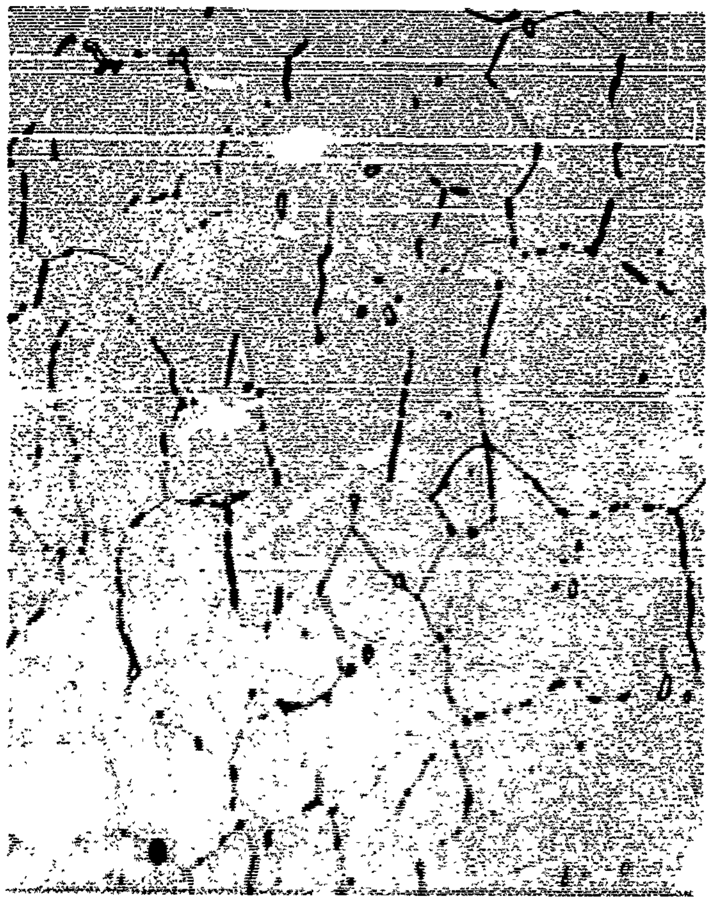


Fillet-Radius

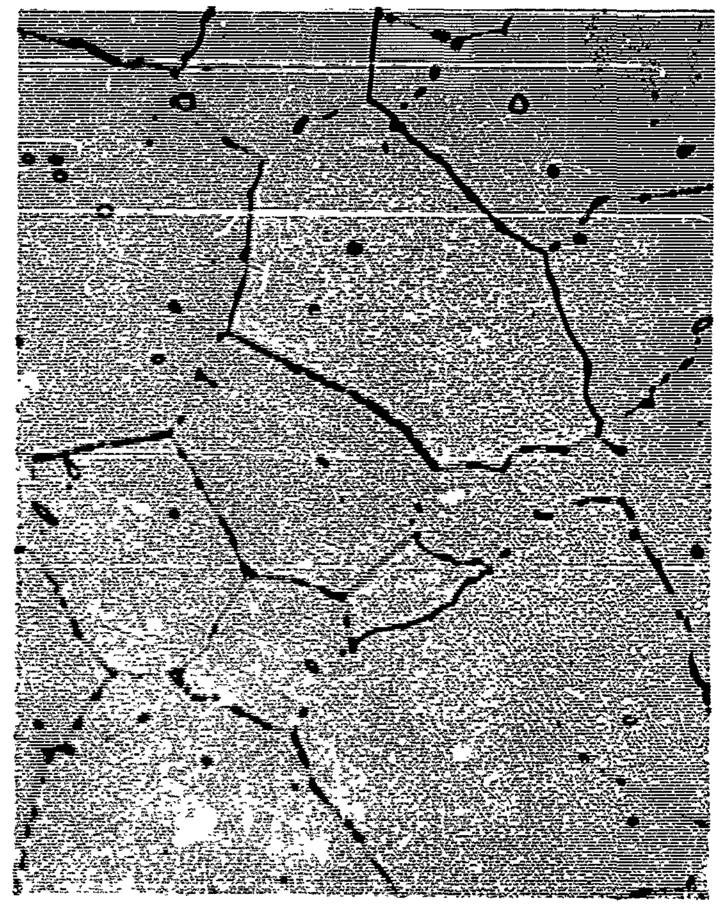
Etchant: 10% NaOH - Electrolytic
Magnification: 250X

FIGURE 34

Transverse Microstructures at the Back Location of Powder Metallurgy TZM H-Shaped Extrusion No. 36 From 2800F Billet Temperature



Corner



Fillet-Radius

Etchant: 10% NaOH - Electrolytic
Magnification: 1500X

FIGURE 35

Transverse Microstructures at the Back Location of Powder Metallurgy TZM H-Shaped Extrusion No. 36 From 2800F Billet Temperature

Location	DPH
At corners	193
	212
	197
	201
Between corners and fillet radii	201
	199
	203
	210
Fillet radii	182
	182
Stem center	203

The average of these values is 198 DPH. As expected, low hardness was found in the fillet radii.

Chemistry

Carbon analysis of extruded material was found to be 0.026 percent by the conductometric method. The carbon range of the original sintered billets was 0.014 percent to 0.032 percent.

Tensile Properties

Two longitudinal sub-standard tensile specimens of 1/4-inch by 1-inch gage section were prepared from flange material at the back location of Extrusion No. 36. Room temperature tests were made without prior heat treatment. Strain rate in these tests were 0.005-inch per inch per minute in the elastic range up to 0.6 percent off-set and 0.05-inch per inch per minute in the plastic range. The results were:

Ultimate Strength (ksi)	Yield Strength (ksi)	% Elongation
68	63	2
71	64	4

Percent elongation values were considerably below similar values listed in Table 20 for tensile tests of arc-cast TZM Extrusions Nos. 22 and 23.

CONCLUSIONS AND RECOMMENDATIONS

The low ductility of as-extruded powder metallurgy TZM could be related to the presence of second phase observed in the microstructure. A thorough investigation of the relationship with this second phase and chemistry and/or heating followed by large deformation is not within the scope of this program. It should be remembered that with low ductility material, considerable difficulty could be expected in the mill operations of straightening, pointing and drawing.

Nevertheless, the extrusion to "H" shape of a powder metallurgy billet, already on hand, from a 2600F billet temperature should be done since (1) a more air-free furnace will be made available for this program, and (2) a possibility of improved ductility as the result of lower billet temperature.

On the other hand, considerable activity is underway at Sylvania to lower gas content in billet material. The consideration for the extrusion of powder metallurgy TZM should be reveiwed if and when improved material should become available.

REFERENCES

1. Santoli, P. A., "Extruding and Drawing Molybdenum to Complex Thin H-Section," Second Interim Technical Engineering Report, RTD Interim Report 8-112 (II), Air Force Contract AF 33(657)-11203, January 1964.

2. Santoli, P. A., "Extruding and Drawing Molybdenum to Complex Thin H-Section," Third Interim Technical Engineering Report, RTD Interim Report 8-112 (III), Air Force Contract AF 33(657)-11203, May 1964.

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Sixteen H-shaped extrusions (14 TZM and 2 stainless) were made with new support tooling. No failure or distortion occurred in the tooling, regardless of liner pressure up to 237,000 psi. Reasonable quality and dimensional runout were found in TZM extrusions

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The use of pressed and sintered solid zirconia nibs was demonstrated successfully for the extrusion of "H" shapes. Dimensional runout for both stainless and TZM was remarkably good and liner pressures were lower than that required for extrusions with segmented, coated dies.

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